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The Joint Cruise Missiles Project: An Acquisition History

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On page 37, second sentence of the second paragraph should read:

> Based upon a 1-1/2 and 2-1/2 year time to Follower qualification, Boeing would have obtained orders to produce approximately 1/6 to 1/3 of the total buy before the actual competition began with the Follower.

Likewise, the first sentence of the last paragraph on the same page should read:

> If a Leader/Follower program were applied today, Boeing would have obtained orders to produce approximately 1/2 to 2/3 of the total buy before the actual competition began with the Follower, based upon a 1-1/2 and 2-1/2 year time to Follower qualification, respectively.

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This report has two objectives: first to record in some detail how the Cruise Missiles Project was organized and managed, and second to provide a preliminary evaluation of the management methods. Section II summarizes the project origins, including a review of cruise missile development before the formation of the joint office and how the Joint Cruise Missiles Project Office originated. Section III identifies the major management issues involved in the project and describes the management techniques used. Section IV presents the limited assessment of project outcomes that is possible at this time. Additional details are included in the appendixes, published separately as "The Joint Cruise Missiles Project--An Acquisition History: Appendixes," Rand N-1989, August 1982.

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PREFACE

An important part of the process of improving acquisition management methods is the accumulation of experience from on-going or recently completed projects, especially if those projects involved unusual situations or innovative management techniques. This report documents the experience to date of one such activity: the Joint Cruise Missiles Project. The research, sponsored by the Joint Cruise Missiles Project Office (a joint Navy/Air Force effort), examines the organization and management methods used by that office from its formation in 1977 until mid-1982, the cutoff date for the research reported here.

Although the 1977 DSARC II decision memorandum that initiated the Joint Cruise Missiles Project also called for studies of advanced cruise missile technology, such projects are not discussed in this report.

Additional explanatory material in the form of several appendixes is available in a separate volume: E. H. Conrow, G. K. Smith, and A. A. Barbour, "The Joint Cruise Missiles Project: An Acquisition History—Appendixes," The Rand Corporation, N-1989-JCMPO, August 1982.

SUMMARY

Over the past three decades, several different general acquisition strategies and numerous detailed management styles and tactics have been tried in an attempt to better predict and control acquisition project outcomes. Improvements have been sought through changes in the types of contracts, the type and extent of competition, the amount of management reporting and review at different levels, the distribution of responsibility between industrial contractor and the Service project office, etc. Yet the goal of a highly predictable and controllable project has proved elusive. Costs grow almost inexorably, schedules slip, and the final product yields performance different (sometimes better, more often somewhat worse) than expected.

An important part of the process of improving acquisition management methods is the accumulation of experience from on-going or recently completed projects, especially if those projects involved unusual situations or innovative management techniques. This report documents the experience to date of one such activity, the Joint Cruise Missiles Project, which involves some unusual situations and innovative techniques that may be applicable to future similar activities:

1. It is a joint endeavor, developing and producing missiles for both the Air Force and the Navy.
2. A family of missiles is being developed concurrently, with a high degree of commonality between models and incorporating advanced technology and performance capabilities.
3. Competition was maintained until the end of ALCM full scale development, a rarity in major weapon system acquisition.
4. An unusual degree of competitive dual sourcing has been introduced in the production phase, thus reducing risks of interrupted or unsatisfactory production and improving opportunity for cost control. As a result of this strategy, the project office has dealt directly with an extensive set of associate contractors rather than one single prime contractor.
5. Production quality assurance has been sought through extensive use of warranties and competitive dual sourcing.

Any one of these features is rare in recent weapon system acquisition, and the combination of all five makes this activity unique. Thus it deserves special attention so we can learn as much as possible about how the project management was structured, how well the structure and procedures worked, and which of the management techniques might be applied to other activities.

Our study objective is twofold: first and foremost, to record in some detail how the project was organized and managed, while the records and key management people are still available; and second, to provide a preliminary evaluation of the management methods used. The scope of the study is limited in two dimensions. First, we examine mainly the events since 1977 when the joint project office was formed. Second, we are concerned only with the technical and organizational issues involved in managing the joint cruise missiles project, and not in developing a complete and detailed project history or in examining questions such as whether such missiles should be developed or how they contribute to our strategic and tacti-

cal force posture. Although such "external" issues are certainly important, they have been addressed extensively in books and newspapers.

This large and complex project involves a family of related but individually distinct missiles developed for use by the Air Force and the Navy. Although only limited operational experience has been accumulated to the time when this research was concluded (mid-1982), test results indicate those missiles that have completed development have met or exceeded almost every performance goal. Some cost growth has been experienced, mainly in the launch and support equipment; the costs of the missiles themselves have grown very little. The main elements of the project are summarized below.

JOINT OFFICE OPERATION

The DSARC II decision memorandum of January 14, 1977, mandated the formation of a joint Air Force-Navy project office with the Navy as lead service and Captain (now Rear Admiral) Walter M. Locke as project director. His charter was to develop the air launched cruise missile (ALCM) for the Air Force, and to develop for the Navy a sea-launched (ship and submarine) (SLCM) and for the Air Force a ground-launched (GLCM) version of the General Dynamics "Tomahawk" missile system. The direction was amended on September 30, 1977, to include a flyoff between Boeing and General Dynamics for the role of strategic ALCM contractor. An additional variant of the Tomahawk, the Medium-Range Air-to-Surface Missile (MRASM) for both Air Force and Navy use, was added three years later. Admiral Locke was also directed to achieve maximum commonality among the various missiles, specifically by using common engine and land-attack guidance systems. After extended negotiations between the two services, final details on organization and division of responsibilities for a Joint Cruise Missiles Project Office (JCMPO) were resolved on September 30, 1977, in a directive from Dr. William Perry, the Under Secretary of Defense for Research and Engineering. That directive also established an Executive Committee, which was chaired by Dr. Perry and included senior representatives of both Services, together with other OSD officials. The Executive Committee met periodically, was able to quickly resolve issues as they arose, and expedited the reallocation of funds as necessary in a complex, dynamic acquisition project.

The joint project office maintained a staff that grew to more than 300 people, split almost evenly between the two Services. Having project management for all missile versions in one office provided maximum opportunity to rigorously control the configuration to ensure maximum component commonality among all missile models. When Boeing was selected in 1980 to produce the ALCM for the Air Force, program management of that missile moved to Air Force facilities at Wright-Patterson AFB. Even then, the engine and major elements of the guidance system remained common for all variants of the cruise missile family. The development and production of several missiles, designed to do different tasks and to be operated by different services, but still retaining a high degree of commonality, was a major management task for the joint office and provided an opportunity to achieve important savings in development and production costs over the life of the project.

MANAGEMENT AND CONTRACTING STRATEGY

The JCMPO's management strategy emphasized the extensive use of dual, competitive sources for all major elements of the missiles. Early in the project a second source was quali-

fied for the sustainer engine. It is expected that both firms will competitively share production throughout the life of the project. Similarly, the inertial navigation element of the guidance system was "broken out," a second source was qualified, and both suppliers competitively share in production. Several other elements of the system have been, or are now being, broken out and second sources introduced to permit redundant production facilities and an opportunity for continuing competition during production.

The latest, and largest, dual-sourcing arrangement introduced by the JCMPO requires General Dynamics (Convair Division) and McDonnell Douglas Astronautics Corporation, suppliers of the SLCM/GLCM/MRASM airframes and guidance system respectively, to cross-license their designs and exchange technologies so that each firm can produce a complete flight vehicle. In addition to providing an expanded production base and creating a competitive environment for future missile production, this arrangement is expected to make it possible for each firm to warrant the reliability and overall quality of the entire flight vehicle as delivered to the government, excluding certain government-furnished items such as the engine. The engine, inertial navigation element, and ALCM airframe have been separately warranted, with the objective of providing the contractors with a substantial and continuing incentive to maintain high production quality.

Throughout the development phase, cost-plus-award-fee contracts were typically used, with a provision that allowed JCMPO to provide a structured set of incentives to the developers. As the project moved into initial production, fixed-price-incentive-fee contracts were used, and as development matures the contracts are being shifted to firm fixed price. Multiyear contracts are being considered for use in future procurement of some elements of the project.

PROJECT OUTCOMES

It is too early to make any definitive assessment of the final consequences of the various management methods used in this project. Only the ALCM has a very long production history, and the MRASM is still early in its development phase. However, some partial and preliminary indications of outcomes can be expressed at this time.

Unfortunately, even under the best of conditions acquisition management effectiveness is difficult to assess. The most common approach is to compare the project outcomes (measured by system performance, schedule, and cost) with the goals established at the beginning of the project. Although yielding quantitative answers, that approach has two obvious limitations: The project manager of record at the end of the project is rarely the same person who participated in the formulation of the goals at the beginning of the project; and many changes occur from outside the project manager's sphere of control (budgets are modified, performance goals are changed, the quantities scheduled for procurement are changed, etc.). Despite these limitations, we provide a preliminary assessment of the project by comparing actual outcomes, or current projections of future outcomes (in terms of system performance, project schedule, and project cost), with the goals established in January 1977 when the JCMPO was formed and full scale development of the ALCM, SLCM, and GLCM were authorized. However, we emphasize that this assessment is little more than a glimpse taken roughly midstream in the life of a large, complex acquisition project, particularly for the GLCM and SLCM projects. These results will almost certainly be modified as additional events unfold and as the full consequences of earlier management policies and actions become more apparent. We strongly encourage subsequent studies that would build on the foundation presented

here and that could provide a more complete and balanced assessment of the overall project organization and management.

System Performance

To avoid security restrictions, we present all performance comparisons in the form of ratios: [test results] divided by [approved project goals]. In some cases a large ratio is desired (missile range, for example, where more is better) and in other cases a small ratio is desired (missile CEP, for example). To permit aggregating the results for several different performance parameters, and to be consistent with long-standing convention when dealing with cost results (discussed below), we inverted the ratios for such parameters as missile range so that in all cases a ratio less than unity is desirable.

Aggregating the ratios for all performance parameters reported in the Selected Acquisition Report (SAR) for each missile system yielded values of 0.94 for the ALCM, 0.86 for the anti-ship SLCM, 0.79 for the nuclear-armed land-attack SLCM, and 0.85 for the conventionally armed land-attack SLCM.[1] That is, in all cases the aggregate measure of system performance was better than that established as a goal in the SARs at the beginning of full scale development.

Project Schedule

Schedule compliance was measured in a manner analogous to the approach used for system performance. We calculated a ratio for each schedule parameter by comparing the number of months actually taken in its accomplishment from the beginning of full scale development with the number of months originally scheduled in the initial approved project. The average of the individual ratios determined for each cruise missile variant was then obtained to yield a schedule ratio. Only schedule parameters actually achieved as of March 1982 were included.

The ALCM was the only cruise missile variant to have reached the DSARC III stage before our March 1982 SAR cutoff date. The average of the ALCM schedule ratios was 1.05, representing a slight schedule slip compared with the initial approved program schedule. The proposed DSARC III date for the ALCM, as defined at the time of DSARC II, was May 1980. The actual DSARC III occurred in April 1980. This included the ALCM flyoff, not envisioned at DSARC II, so the net schedule compliance was better than the average schedule ratio value indicates.

Determination of the GLCM and SLCM schedule ratios did not prove possible. In the GLCM case, only one schedule event was reported being completed (besides the DSARC II) in the March 1982 SAR, although five other events from the initial approved project were scheduled to be completed before this cutoff date. A schedule slippage moved the GLCM project initial operational capability (IOC) date back 21 months from the March 1982 date given for the initial approved project, but that appears to have been caused largely by forces external to the project. As of March 1982 the GLCM DSARC III was scheduled for May 1983, and the IOC for December 1983.

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[1]When this report was written, GLCM performance data were unavailable. However, the GLCM performance ratios should be similar to those of the nuclear armed land-attack SLCM.

Quantification of the project schedule for the SLCM proved even more difficult to perform than for the GLCM. The schedule, including the IOC, of both land-attack SLCM variants was strongly affected by external influences from the NATO High Level Group, the President, and the Congress. Similarly, the anti-ship SLCM was affected by external events, including reductions in the FY80 budget. These complications and the resulting difficulty they would impose on the SLCM schedule ratio calculations prevented our performing this analysis.

Project Costs

Cost changes are most easily described in terms of cost growth ratios (defined as the Current Estimate divided by the baseline Development Estimate). However, comparison of such cost growth ratios for several programs can be misleading if the programs cover different time spans. Program cost tends to increase with the passage of time. Therefore, we emphasize the average annual *rate* of cost growth for comparison purposes.

We made two adjustments in the raw cost data when generating the cost ratios and growth rates presented below. First, we translated all cost values into constant base year (FY77) dollars, thus removing the effects of inflation. Second, the procurement cost changes were normalized to the baseline (Development Estimate) quantity.

The ALCM program exhibited a normalized cost ratio of 1.23 for the total program through March 1982, most of the growth occurring in 1980 and 1981. This represents an annual cost growth rate of 4.4 percent. The average annual growth rate of the ALCM program *development phase* cost was 7.8 percent. The *procurement phase* cost exhibited a growth rate of 3.0 percent. During this phase the annual growth rate of ALCM *missile* procurement cost was only 2.0 percent, while it was 11.8 percent for support equipment.

The SLCM project experienced a total normalized cost ratio of 1.54 through March 1982. This represents an annual cost growth rate of 10.4 percent. The average annual growth rate of the SLCM program *development phase* cost was 7.5 percent. The *procurement phase* cost exhibited a growth rate of 12.6 percent. The average annual growth rates in the procurement cost of the anti-ship and the average of the two land-attack SLCM variant *missiles* were 2.8 percent. The procurement cost of the launch equipment experienced an average annual change of 50.2 percent and other support equipment 41.7 percent.

The GLCM program experienced a total normalized cost ratio of 1.93 through March 1982, an annual cost growth rate of 17.6 percent. The average annual growth rate for the GLCM program *development phase* was 44.1 percent, almost entirely because of cost growth in the launch and support equipment. The total GLCM program *procurement* cost had a net average annual growth rate of 13.1 percent, with the increase due solely to cost increases that were not missile related. The average annual rate of growth for procurement cost of the GLCM *missile* was −2.7 percent, for procurement of the launch equipment was 86.4 percent, and for other support equipment was 16.8 percent.

These rates of cost growth may be compared with typical experiences from other projects. A survey of 20 "mature" weapon systems (at least three years past the beginning of full scale development) developed during the 1970s yielded an average annual growth rate of 6.3 percent for the development phase, 3.8 percent for the procurement phase, and 7.2 percent for the total program. The ALCM total program falls slightly below the historical aggregate average, whereas the SLCM and GLCM programs are on the high side. The cost growth rate during the procurement phase of the three cruise missile *air vehicles* falls below the historical average of procurement experience, while all other procurement categories exceed the historical rate of cost growth. Although the support categories for the ALCM and GLCM programs

show moderate procurement cost increases, that for the SLCM project shows a large increase. Similarly, launch equipment for the GLCM and SLCM programs show large cost increases in procurement cost. Those increases were mostly due to requirements added after the beginning of the full scale development program, and as such were beyond the control of the JCMPO.

ACKNOWLEDGMENTS

This research could not have been completed without the exceptional cooperation and assistance from many members of the Joint Cruise Missiles Project Office. In addition to Rear Admiral Walter M. Locke, who provided invaluable support throughout the project, we are especially indebted to Col. Carey Daniel, Deputy Project Director, and his secretary, Ms. Nancy Sanchez; Mr. Theodore F. Fredman, Legal Counsel; Capt. Walter Austin (USN), Director of Acquisition, and three of his key managers: Mr. William Parkin, Executive Director of Acquisition; Cmdr. James Hooker, Director of the Contracts Division; and his successor in that position, Mr. Brian Polly. We also owe special thanks to Capt. Harry M. Yockey (USN), Manager of Submarine Launched Systems; Mr. Otto Sanders, Director of Test and Evaluation; Lt. Col. Stanley C. (Bud) Green, Deputy Manager of the MRASM; Capt. John Clinton (USN), Director of Product Assurance and Manufacturing, and Major Donald Alducin, Director of the Production Division; and Mr. George E. Schubert, Project Technical Director. Also invaluable for their assistance in providing copies of project documents were Mr. Robert E. Holsapple, Director of Public Affairs, and the entire staff of the Management Information Systems Division. Ms. Tammy J. Walker of the Sea Launched Project provided meticulous historical records of external directives. Finally, Mr. Howard Hurley, Deputy Director, Resources Management Division, and Maj. Daniel King, Chief of the Budget Preparation Office, provided information on project costs.

We also received valuable assistance from several people who are no longer associated with the JCMPO, especially Cmdr. Bruce Avery (USN, ret.), Col. Alan Chase (USAF, ret.), Capt. Joseph Hanzel (USN), and Dr. Michael Beltramo.

We greatly appreciate the assistance of current and former members of the Defense Mapping Agency for providing cost analysis data and information pertaining to their relationships with the JCMPO, which have contributed to the success of the cruise missile project. Finally, we want to express our thanks for the help of Col. Joseph Rutter and his staff at the Air Force ALCM System Project Office.

The authors are, of course, solely responsible for the accuracy and interpretation of the information presented in this report.

GLOSSARY

ABL	Armored box launcher
ACE	Alternate cruise engine
ACSM	Advanced conventional standoff missile
AFSC	Air Force Systems Command
AGM	Air to ground missile
ALCM	Air launched cruise missile
ASD	Aeronautical Systems Division of AFSC
AUR	All-up round
CMGS	Cruise missile guidance set
CNM	Chief of Naval Material Command
COMOPTEVFOR	Commander, Operational Test and Evaluation Forces
CWCS	Common weapon control system
DCASPRO	Defense contract administration services plant representative office
DDR&E	Director of Defense Research and Engineering (later USDR&E)
DMA	Defense Mapping Agency
DSARC	Defense Systems Acquisition Review Council
DSMAC	Digital Scene Matching Area Correlator
DT	Development testing
DTC	Design to cost
ECP	Engineering Change Proposal
EXCOM	Executive Committee
FSD	Full scale development
GAC	Goodyear Aerospace Corporation
GD/C	General Dynamics Corporation, Convair Aerospace Division
GFE	Government furnished equipment
GLCM	Ground launched cruise missile
IIR	Imaging infrared
INE	Inertial navigation element
INS	Inertial navigation system
IOC	Initial operational capability date
ISA	Inertial sensor assembly
JCCB	Joint configuration control board
JCMPO	Joint Cruise Missiles Project Office
JEPO	Joint Engine Project Office

JSTPS	Joint Strategic Target Planning Staff
LCC	Life cycle cost
LG&CS	Litton Guidance and Control Systems
LSL	Litton Systems Limited of Canada
LTV	Ling Temco Vought Corporation
MDAC	McDonnell Douglas Astronautics Company
MOA	Memorandum of Agreement
MRA	Missile radar altimeter
MRASM	Medium range air to surface missile
MYP	Multi year procurement
NAC	Naval Avionics Center
OIDT	Operator interface display terminal
O&S	Operations and Support
OSD	Office of the Secretary of Defense
OT	Operational Testing
PMD	Program management directive
RASS	Random access storage system
REM	Recovery Exercise Module
RFP	Request for proposal
RFQ	Request for quotation
SAC	Strategic Air Command
SAR	Selected acquisition report
SCAD	Subsonic cruise armed decoy
SLCM	Submarine launched cruise missile (original meaning) Sea launched cruise missile (current meaning)
SPOC	System Project Officers Council
SRAM	Short range attack missile
STCM	Supersonic tactical cruise missile
TAAM	Tomahawk Airfield Attack Missile
TATE	Tooling and test equipment
TCAE	Teledyne Corporation, Continental Aircraft Engine Division
TDP	Technical data package
T&E	Test and evaluation
TERCOM	Terrain contour matching
UFC	Unit flyaway cost
WIC	Williams International Corporation

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

The management of a major weapon system acquisition project is an exceptionally challenging task. Most such activities involve attempts to integrate several major subsystems, each of them being simultaneously developed against ambitious performance goals, with the overall system to be committed to high rate production at the earliest possible time. The management process involves the continual balancing of multiple risks and uncertainties and the frequent restructuring of project elements and schedules as the hardware development advances and external project goals and constraints evolve.

Given the technical complexity of the management task, the large amounts of money frequently involved, and the political and military consequences riding on the outcomes, it is understandable that considerable attention and effort have been devoted to improving the methods of military systems acquisition management. Over the past three decades several different general acquisition strategies, and numerous detailed management styles and tactics, have been tried in an attempt to improve the prediction and control of project outcomes. Improvements have been sought through changes in the types of contracts, the type and extent of competition, the amount of management reporting and review at different levels, the distribution of responsibility between industrial contractor and the service project office, etc. Yet the goal of a highly predictable and controllable project has proved elusive. Costs grow almost inexorably, schedules slip, and the final product yields performance different (sometimes better, more often somewhat worse) than expected.[1] The specific sources of difficulty may vary from one project to the next, but a few basic issues are remarkably enduring: how to ensure that cost and performance estimates made at the beginning of a project are realistic, ensure management access to timely and accurate information about project status, and structure the project so that management at each level can in fact control the thrust of effort in the organization. Thus, the search for improved management methods continues.

An important part of the process of improving acquisition management methods is the accumulation of experience from on-going or recently completed projects, especially if those projects involved unusual situations or innovative management techniques. This report is devoted to documenting the experience from 1977 to mid-1982 of one such activity: the Joint Cruise Missiles Project. That project involves some unusual situations and innovative techniques that may be applicable to future projects:

1. It is a joint project, developing and producing missiles for both the Air Force and the Navy.
2. A family of missiles is being developed concurrently, with a high degree of commonality between models, and incorporating advanced technology and performance capabilities.
3. Competition was maintained until the end of ALCM full scale development, a rare occurrence in major weapon system acquisition.

[1]For an accounting of how project outcomes have differed from expectations over the past two decades, and of the effects of some different management strategies, see Edmund Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, The Rand Corporation, R-2516-DR&E, October 1979.

4. An unusual degree of competitive dual sourcing has been introduced in the production phase, thus reducing risks of interrupted or unsatisfactory production and improving opportunity for cost control. This strategy has resulted in the project office dealing directly with an extensive set of associate contractors rather than a single prime contractor.
5. Production quality assurance has been sought through extensive use of warranties and competitive dual sourcing.

Any one of these features is rare among recent and current weapon system acquisition projects, and the combination of all five makes this project unique. Thus it deserves special attention in order to learn as much as possible about how the project management was structured, how well the structure and procedures worked, and which of the management techniques might beneficially be applied to other projects.

STUDY OBJECTIVES AND SCOPE

Our study objective is twofold: first to record in some detail how the project was organized and managed, while the records and key management people are still available; and second to provide a preliminary evaluation of the management methods. It would be desirable to include a thorough analysis of the project, showing the extent to which each management goal had been achieved and why it came out that way, but in only a few cases has enough evidence been accumulated to permit such conclusions. A definitive analysis will have to wait until several more years of experience have been accumulated, but by then many of the procedural details employed in the project may have been lost. Thus our present study is aimed at making an initial contribution to the overall assessment.

The scope of the study is limited in two dimensions. First, we examine mainly the events since 1977 when the joint project office was formed. Each service had an active cruise missile development project for several years before that time; we briefly review that earlier period to provide some historical continuity, but we are mainly interested in the joint Navy-Air Force phase of the project. Second, we are concerned only with the technical and organizational issues involved in managing the joint cruise missiles project, and not in developing a complete and detailed project history or in examining such questions as whether such missiles should be developed or how they contribute to our strategic and tactical force posture. Although such "external" issues are certainly important, they have been addressed elsewhere.[2]

ORGANIZATION OF THE REPORT

For readers not familiar with the Joint Cruise Missiles Project, Sec. II summarizes the project origins, including a review of cruise missile development before the formation of the joint office, and how the Joint Cruise Missiles Project Office (JCMPO) originated. In Sec. III we identify the major management issues involved in the project and describe the management techniques used; and in Sec. IV we present the limited assessment of project outcomes

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[2]See, for example, Richard K. Betts (ed.), *Cruise Missiles: Technology, Strategy, Politics*, The Brookings Institution, Washington, D.C., 1981. This book is a collection of 15 papers, by different authors. Although the papers are inevitably of uneven quality, they do provide a historical overview of some of the strategic and political arguments regarding the use of cruise missiles.

that is possible at this time. Additional details of project organization and management procedures are included in the appendixes, published separately as E. H. Conrow, G. K. Smith, and A. A. Barbour, "The Joint Cruise Missiles Project: An Acquisition History—Appendixes," The Rand Corporation, N-1989-JCMPO, August 1982.

II. PROGRAM ORIGINS

Following the end of World War II, both the Air Force and the Navy instituted vigorous attempts to develop cruise missile systems, but the primitive state of guidance and jet engine subsystem development at that time severely limited performance. By the mid to late 1950s, enough technological advances had been made to justify production of a few designs, but they were quickly supplanted by ballistic missiles in the strategic deterrent forces. The technologies continued to advance in the following years, as jet engine improvements were supported by many manned aircraft programs and as smaller, more accurate and reliable missile guidance systems were introduced. By the early 1970s both services were formulating new concepts for cruise missiles as part of their strategic forces. In this section we will briefly summarize the cruise missile programs of the two services during the first half of the 1970s, how those programs were merged with the formation of the Joint Cruise Missiles Project Office in 1977,[1] and the events that led to a competitive flyoff for selection of an ALCM design.

EARLY PHASES OF CRUISE MISSILE DEVELOPMENT

In the early 1970s the Air Force cruise missile program emphasized development of a Subsonic Cruise Armed Decoy (SCAD) for use in degrading enemy defenses that might be used against the B-52. In June 1972, a contract was awarded to The Boeing Aerospace Company for the SCAD airframe and for the necessary B-52 modifications, and another contract was awarded to Litton Industries' Guidance and Control Systems Division (LG&CS) for the missile guidance. A month earlier, contracts had been awarded to Williams International Corporation (WIC)[2] and Teledyne Corporation, Continental Aircraft Engine Division (TCAE) for an eight-month competitive turbofan engine development program, with Williams declared the winner in April 1973. Similarly, in 1971 TCAE had won a competitive contract to develop a lightweight, low cost, expendable turbojet engine (J402) for the Harpoon, the precursor to the Navy cruise missile project.

In mid-1973, development of the SCAD missile was stopped because of growing uncertainty over the need for that particular missile. However, the Air Force continued to work on technology areas critical to early development of a cruise missile, including further development of the Williams engine.

During the early 1970s the Navy was becoming interested in both tactical and strategic cruise missiles. Partially in response to a growing Soviet surface fleet and cruise missile threat, the Navy conducted studies in 1970-1971 to analyze the feasibility of developing a submarine launched cruise missile. That activity was initially channeled through a separate program element within the Navy Harpoon project office termed Cruise Missiles (Advanced).

[1]Some of the material in this chapter was drawn from T. J. Canfield and R. A. Kellett, Jr., "Cruise Missile: An Examination of Development Decisions and Management," a Masters thesis submitted to the Naval Postgraduate School, March 1978.

[2]Originally known as Williams Research Corporation, the name was changed to Williams International Corporation in June 1981. For simplicity, the new name will be used throughout this report.

Secretary of Defense Melvin Laird supported the project and requested Congressional funding for a strategic cruise missile in a FY72 Supplemental Appropriation.

In October 1972, the Harpoon project office issued a Request For Quotation (RFQ) to 12 qualified contractors to perform airframe design studies of a strategic SLCM. Aerodynamic design study contracts for SLCMs using both vertical and horizontal (torpedo) tube launch were issued in December 1972 to The Boeing Aerospace Company, Convair Aerospace Division of General Dynamics (GD/C), Lockheed Missiles and Space Company, McDonnell Douglas Astronautics Company (MDAC) (developer of the Harpoon), and Vought Systems Division of Ling Temco Vought Aerospace Corporation (LTV). By March 1973, the Navy cruise missile airframe design studies had been completed and each contractor had conducted wind tunnel tests. Earlier, the Navy had awarded guidance and navigation design study contracts to E-Systems Corporation for a terrain contour matching (TERCOM) navigation subsystem and to Goodyear Aerospace Corporation for a range-only correlation system. By April 1973, E-Systems had completed the study and had successfully demonstrated the TERCOM guidance concept using a breadboard guidance system installed in a pod mounted under the wing of an A-7 aircraft.

In April 1973, the Naval Air Systems Command issued a formal charter for a new project office, headed by Captain Walter M. Locke, with responsibility for development of the Navy SLCM. By that time the technical feasibility of an accurate, long-range cruise missile had been demonstrated.

There were also indications by mid-1973 that future missile development programs would involve at least some cooperation between the Air Force and the Navy. Deputy Secretary of Defense William Clements terminated engineering development of the SCAD program on June 30, 1973. A supplementary memorandum from Dr. Currie on July 30, 1973, instructed the Air Force to cooperatively support Navy work on TERCOM guidance and to begin an effort involving carrier aircraft equipment integration design associated with the Navy cruise missile project. That effort was not merely to design carrier aircraft equipment but to aid in the optimization of the cruise missile/carrier aircraft configuration. In August 1973, Mr. Clements directed the Navy to defer launch platform decisions for the SLCM because it appeared feasible to develop a single basic missile design that could be launched from sea, air, and land platforms. In addition, the Navy was to initiate a program including prototype vehicles for flight test by each of two competitive contractors. At least some members of OSD were considering the Navy land attack SLCM for possible use in an air launched role (including use on strategic bombers).

A RFQ was issued in August 1973 for a competitive advanced development SLCM effort, to include test demonstration and launch vehicle compatibility studies of strategic and tactical SLCM prototypes. In December 1973, Mr. Clements authorized the Navy to continue with the SLCM project; he also authorized the Air Force to proceed with an ALCM that would build on the earlier SCAD experience. At the same time, he noted the similarity between the Air Force and Navy missiles and, to avoid unnecessary duplication, directed that the Air Force should be responsible for developing an engine suitable for use in both missiles, while the Navy was to develop a land-attack guidance system for both missiles.

Source selection for the SLCM airframe was completed in December 1973; and, following a DSARC I review in February 1974, competitive demonstration contracts were awarded to GD/C and LTV for design, development, fabrication, and demonstration of prototype cruise missiles. Although the Air Force had previously chosen the WIC engine for the ALCM, in January 1974 the Navy encouraged them to include a second engine candidate to allow for a competitive flyoff of two different airframe/engine pairings for the SLCM. WIC was a small, privately owned firm at that time, with no experience at production rates that would be

required for the cruise missiles project. The Navy wanted to reduce production risk and identify the best engine by the end of the validation phase.

In April 1974, WIC was paired with GD/C, and TCAE was paired with LTV, in a competition for the Navy SLCM flight vehicle. The competition was structured so that either engine contractor and either airframe contractor could be selected. In a separate competition that also included GD/C and Vought, MDAC and E-Systems were selected to compete in developing land-attack guidance and navigation systems, and both candidate guidance designs were added to both the GD/C-WIC and LTV-TCAE flight vehicle development teams.

Following the December 1973 authorization to develop a long-range strategic ALCM, the Air Force rapidly converted the SCAD design to the new objective. Boeing had been prime contractor on SCAD, and WIC had already been selected to supply the engine, so they continued as contractors for the ALCM. The Air Force designed their program so that they would be ready to start full scale development of the ALCM by the end of 1974, as ratified by the February 1974 DSARC I review.

During November 1974, the Navy sponsored testing of shortened (to 168 in. length) GD/C and LTV candidate SLCMs for physical fit aboard the B-52 internal Short Range Attack Missile (SRAM) rotary rack, thus establishing at least the first order feasibility of using the SLCM in an air launched role. This contributed to considerable debate, extending over the next two years, among the Services, OSD, and the Congress as to whether the SLCM would be used in an air launched role and thus replace the Air Force ALCM.

An ALCM DSARC II and SLCM Program Review was held in December 1974. In the resulting January 1975 decision memorandum, Dr. Malcolm Currie, Director of Defense Research and Engineering, directed that the ALCM should not proceed into full scale development until a complete concept demonstration had occurred, and instead both the Air Force and Navy cruise missile projects should remain in advanced development, which would include limited flight tests of both systems. Dr. Currie also directed that the project schedules be restructured, and that the projects were to maximize commonality at the subsystems level (navigation/guidance and propulsion) so that they could achieve first flight in early 1976.

Following a subsequent DSARC review of both programs in February 1975 a decision memorandum specified the Air Force cruise missile first flight date as February 1976, and the Navy's as March 1976. In addition, the Navy was assigned the responsibility to select a single navigation/guidance contractor for both the ALCM and land-attack SLCM projects with the goal of achieving maximum commonality of navigation/guidance equipment for the two projects. The Navy project office directed both MDAC and E-Systems to revise their development projects to accommodate an accelerated schedule in compliance with the DDR&E decision to complete the competitive demonstration phase by October 1975. LG&CS and Singer Kearfott (SK) had earlier been selected as the major subcontractors to MDAC and E-Systems, respectively, to provide them with inertial navigation components for the TERCOM competitive demonstration.

In March 1975, the ALCM program office provided the Navy project office with the performance requirements for the ALCM guidance system. The Navy project office then directed MDAC and E-Systems to perform initial interface studies to ensure that the ALCM would be compatible with the selected guidance contractor. In May 1975, the project office issued a request for proposal (RFP) for the follow-on phases of the guidance development, which identified progressive phases of development: specifically, a systems integration stage, full scale development, and pilot production. A competitive TERCOM flyoff was held and other evaluations performed on the integrated navigation systems of the two contractors and their inertial navigation subcontractors. In October 1975, MDAC was selected as the winning guidance

contractor,[3] with the concomitant selection of LG&CS as the inertial navigation subcontractor, for the development of the ALCM and SLCM land-attack guidance system.[4]

In the intervening two-year period from the issuance of the competitive development contracts for SLCM to GD/C and LTV, both contractors had designed, developed, and fabricated candidate cruise missiles, which were subjected to a variety of tests, including: observables (radar cross-section), active wind tunnel flight, shock resistance, and B-52 compatibility. On March 5, 1976, the Navy issued a stop work order to LTV, before the completion of the competitive airframe demonstration phase of development, because of a potential $5 million cost overrun. The Navy selected GD/C as the winning contractor on March 17, 1976 (approximately one month ahead of schedule). In May 1976, WIC was named as the developer of the SLCM turbofan engine (in addition to already being the ALCM engine developer).

At that time, a single source for propulsion and guidance subsystems had been competitively selected for use in both the Navy and Air Force cruise missile programs, although each service retained a different airframe design: the Navy SLCM (BGM-109 "Tomahawk") and the Air Force ALCM (AGM-86A).

A second DSARC II review of the Air Force program, and the first such review of the Navy project, were held in January 1977. Before that time, 6 ALCM and 16 SLCM flight tests had been performed. SLCM flights 3-16 were launched from an A-6 aircraft, which presented less risk as a launch platform than a submarine, eliminating the need for the solid rocket booster motor. Consequently, at least a limited proof of concept regarding the basic performance for each vehicle was available. A major issue was whether the Air Force ALCM would be allowed to continue versus using the Navy SLCM in both sea and air launched roles. During pre-DSARC meetings, both Air Force and Navy officials agreed that the SLCM might be favored at DSARC II if only one project was to proceed into full scale development. It was estimated at the time that the selection of the SLCM over the ALCM for the air launched role would save over $100 million in development costs and over $200 million in procurement costs. Furthermore, the SLCM met all existing specifications and mission requirements for the ALCM role. The major penalty apparent at the time was that only six of the Navy SLCMs would fit on an unmodified (B-52) SRAM rotary rack because of its design shape (for torpedo tube launch) versus eight of the Air Force ALCMs, which were specifically designed to fit on this rack. (As was later shown during the ALCM competitive flyoff, however, eight GD/C SLCM variants could be fitted to a modified SRAM rotary rack.)

DSARC II PROGRAM DESIGN

The decision memorandum issued on January 14, 1977, in response to the DSARC II review resolved several of the major issues that had been debated over the previous year or

[3]The inertial navigation components present in each Boeing and GD/C land-attack cruise missile include a Litton inertial guidance platform, digital computer, and power supply, collectively designated the Inertial Navigation Element (INE). A Reference Memory Unit and Computer (RMUC) is an INE along with a radar altimeter and chassis. When the RMUC is integrated into a package, it is known as the Cruise Missile Guidance Set (CMGS), which is provided by MDAC for the GD/C Tomahawk land-attack cruise missile. Boeing takes the INE, provided by MDAC, and adds a separate autopilot and associated computer, and radar altimeter. The result is a distributed navigation/guidance subsystem that is incorporated in their ALCM (AGM-86). MDAC supplies the complete flight software for the GD/C Tomahawk land-attack cruise missiles. Boeing, however, provided the systems integration and software for their ALCM, although MDAC has supplied them with the TERCOM algorithms (as directed by the Navy project office).

[4]At approximately that same time, MDAC was also awarded the SLCM anti-ship guidance contract, which contemplated a modification of its Harpoon guidance system.

two and provided the basis for much of the ensuing cruise missiles project. One topic of debate within the Congress and OSD was the need to maintain not only separate Air Force and Navy cruise missile airframes, but projects as well. One position was that a single project manager, with two project elements and airframe contractors (Boeing for the Air Force and GD/C for the Navy projects respectively) should be formulated. The rationale for this position was that cruise missiles were in their infancy, that maximum progress would be achieved by having two contractors on the project, and that to opt for a single cruise missile might result in unwarranted schedule risk and performance compromises. Having the resulting projects under a single, joint project office, however, offered potential benefits in commonality, testing, and reducing development and production costs. It was recognized that if this option was used it would be advantageous that a single service director be established as its head, and that a deputy director be designated from the other service.

Another position was that the Navy SLCM, having previously passed loading tests on a B-52 SRAM rotary rack and been successfully air launched 14 times before DSARC II, should be used by the Air Force in the strategic air launched role, thus minimizing development costs, and maximizing testing and system commonality. In this case, the resulting project would remain in the Navy project office, which had done a credible job in bringing the Navy SLCM development in phase with the Air Force ALCM, although initially being approximately two years behind.

In his DSARC II decision memorandum, Mr. Clements used elements of both positions to provide a project with minimum performance risk, but maximum commonality. Despite the acquisition cost savings that were predicted to accrue from selecting one common cruise missile airframe, doing so might impose unwarranted performance compromises on both ALCM and SLCM weapon systems. Consequently, the Boeing designed ALCM and the GD/C designed SLCM were passed through DSARC II and authorized to enter full scale development as separate projects. Mr. Clements stated, however, that "considerable benefits still can be realized in joint test and evaluation, in quantity buy of common components, and in management efficiency, by consolidating the two separate Air Force and Navy programs, now independently managed by different program offices." Mr. Clements further directed that a Joint Service Cruise Missiles Project Office (later changed to JCMPO by deleting the word Service) be established with the Navy designated as the executive service and Captain Locke as the project manager to develop the ALCM and GLCM for the Air Force and the SLCM for the Navy.

It was further specified that both land-attack and anti-ship versions of the SLCM were to continue development, and that a new, longer range ALCM (designated AGM-86B, or ALCM-B) was to be developed and given priority over the existing AGM-86A (ALCM-A).[5]

Mr. Clements also directed that a GLCM using the Tomahawk missile was authorized for development starting the following year. The GLCM had not been part of the formal cruise missiles development project, although OSD direction pertaining to a ground launched cruise missile option dates back at least to the SLCM DSARC I, held in February 1974. Some Navy personnel had viewed that launch option as less important than the SLCM, because if it ever were deployed, it would be assigned to either the Army or the Air Force. The Navy considered the ground launched option before DSARC II as a third possibility in their Decision Coor-

[5]The extended range ALCM-B was only a paper design at that time. A second long range ALCM, known as the "class II vehicle" was also briefed at the DSARC II. It was basically an ALCM-A with an external fuel tank. That vehicle had undergone only a limited development before the DSARC II and was not approved for full scale development.

dinating Paper (DCP-125), dated January 7, 1977. There, the Navy proposed developing and testing the submarine/ship-launched land-attack SLCM and, in addition, developing the air-launch and ground-launch capability. Navy involvement with a ground-launch capability also provided a mechanism for testing the feasibility of the ship-launch mode and the future Armored Box Launcher. Preparations had been made for ground launching a SLCM to simulate a ship launch, and the first such test occurred on February 24, 1977, shortly after the DSARC II decision memorandum (January 14, 1977) that established the GLCM project.

The first tasks of the JCMPO were to complete the development, leading to production decisions at DSARC III, of the ALCM and the "Tomahawk variants including the important Air Force GLCM application."[6] The decision memorandum further directed the JCMPO to "maximize subsystem/component commonality and quantity buy, to utilize fully joint test and evaluation, to encourage subsystem/second-source competitive procurement, and to otherwise derive maximum benefit from the joint service management of several separable cruise missile projects." Funding for these tasks was to be consolidated from existing Air Force and Navy approved project elements.

Although the basic mandate for establishing JCMPO had been given in Mr. Clements' decision memorandum, the Air Force and Navy had latitude on many implementation issues. The resolution of those issues will be described in the following section.

Figure 1 shows a schematic of the key milestones of the two service projects before January 1977.

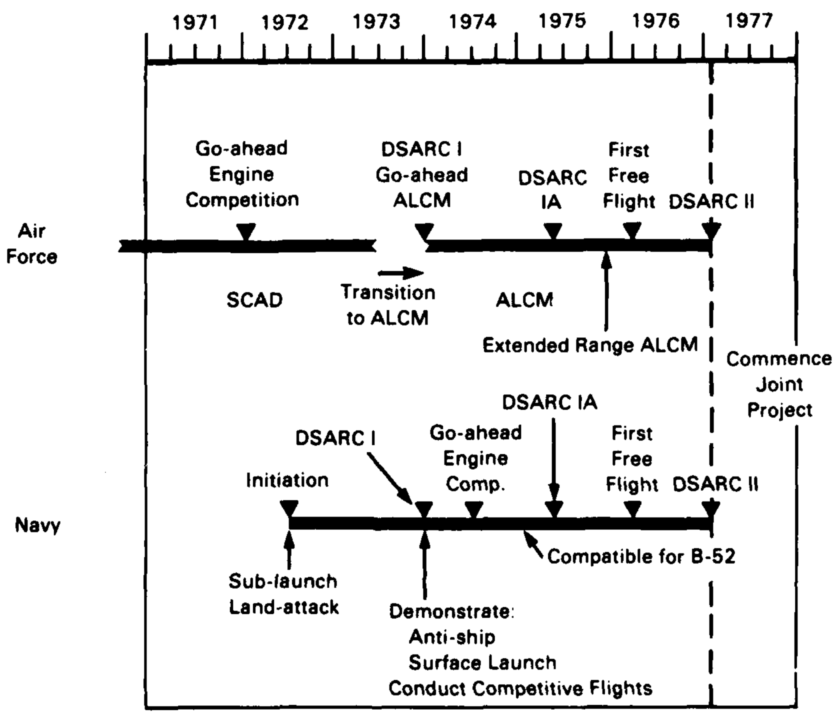

Fig. 1—ALCM/SLCM development history

[6]OSD DSARC II decision memorandum of January 14, 1977.

ALCM COMPETITIVE FLYOFF

Despite the January 1977 DSARC II decision memorandum directing only the Air Force ALCM be developed for air launch, interest continued within OSD, the Congress, and GD/C regarding an air-launched SLCM variant (AGM-109). It was clear that both the GD/C and Boeing candidate missiles would not be produced for this role because of cost and logistical considerations. The GD/C AGM-109 held an advantage in that the SLCM, from which it was derived, had 14 flight tests launched from an A-6 aircraft before DSARC II. Although the Boeing ALCM-A (AGM-86A) had flown before, the ALCM-B (AGM-86B) was still a paper design at that point. The AGM-109 design, moreover, was very close to that of the nuclear-armed land-attack SLCM, so AGM-109 development costs were expected to be considerably lower than those for the AGM-86B. In addition, because both the SLCM and the newly created GLCM showed promise of advancing to the production phase, the GD/C AGM-109 had the potential to be less expensive than its Boeing counterpart because of larger production quantities.

In response to a question at a Congressional Hearing on September 9, 1977, Captain Locke provided the following written response regarding the necessity of holding the ALCM competition:

> The disadvantages are primarily related to cost and schedule risk. The maintenance of competition through Full Scale Engineering Development should insure that the government is offered the best system possible for the lowest cost. The fact that the forces of competition will be in effect at the time that validated production proposals are submitted should offset the cost and schedule risk inherent in the concurrency required by the desired IOC. If a single contractor were chosen now the government would be forced to "buy before fly" since the ALCM-B and Tomahawk (AGM-109) have not demonstrated their system effectiveness from the B-52 to date. Both these long range cruise missiles require development of new launch racks and pylons and must be integrated into the B-52 Avionics Suite. In view of the increased national emphasis now placed on the cruise missile as a part of the Strategic TRIAD, resorting to one contractor for sole source procurement prior to completion of the above development effort could result in significant cost or schedule risk. . . . The flyoff will result in a demonstration of system effectiveness and a proposal for production from each contractor. This should provide the data required for the Department of Defense to choose the best possible system for the Air Launched mission at the lowest possible Life Cycle Cost under minimum risk conditions. Both systems will be required to meet common specifications and operational requirements.[7]

Additional justification for a competitive flyoff was offered by Captain Locke and Dr. William Perry at Congressional appearances during July and September 1977. One factor mentioned[8] was that the competition would require each contractor to demonstrate its capabilities and performance through the stages of preliminary production. That approach might provide valuable insight as to how well each contractor could make a transition from a development program into pilot production before a commitment was made to a single

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[7]Hearings on H.R. 8390, Supplemental Authorization for Appropriations for FY78, Committee on Armed Services, House of Representatives. Statement of Captain Walter M. Locke in response to questions submitted by Mr. John J. Ford, Director, House Armed Services Committee Staff, September 9, 1977, pp. 284-285.

[8]Hearings on S. 1863, Fiscal Year 1978 Supplemental Military Authorization, Committee on Armed Services, United States Senate. Written response to questions submitted by Senator Thomas J. McIntyre, July 29, 1977, p. 106.

missile. A second factor discussed[9] was that if a paper competition was staged, one contractor could not be named the winner without the risk of the other immediately filing a protest. It was stated that at least a paper source selection would be necessary to avoid a protested decision, although that might not provide enough information to determine which missile was best suited for the ALCM role.

The formal competition between the two companies was announced on September 30, 1977. In his memorandum to the Secretaries of the Air Force and Navy, Dr. Perry stated: "It was a matter of the highest national priority, especially in light of the B-1 decision, to develop an ALCM with optimal performance, and minimum cost and schedule delays." He ordered a competitive flyoff between the Boeing (AGM-86B) and GD/C (AGM-109) candidate cruise missiles to determine which one would be procured. He further ordered that the ALCM competition be conducted by the JCMPO (which would at least be retained through the ALCM DSARC III) and include operational tests with crews from the Strategic Air Command. Finally, he specified the structure of the source selection advisory committee and nominated the Secretary of the Air Force to be the source selection authority who would determine the outcome of the competition.

The flight test portion of the competition started on July 17, 1979, and ended on February 8, 1980. On March 25, 1980, Boeing was selected as the ALCM competition winner; and shortly thereafter the ALCM program began the transition process from JCMPO in Washington, D.C., to the Aeronautical Systems Division (ASD) at Wright Patterson Air Force Base. By June 1980, that process was nearly complete. Although the ALCM program management was relocated to ASD, engine and guidance systems management was retained at JCMPO to ensure commonality between cruise missile variants.

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[9]Hearings on the Department of Defense Appropriations for 1978, Subcommittee of the Committee on Appropriations, House of Representatives, September 20, 1977, p. 330.

III. KEY ELEMENTS OF PROJECT ORGANIZATION AND MANAGEMENT

The joint cruise missiles project is exceptionally complex.[1] This section summarizes four elements that seem especially important to an understanding of the management organization and procedures: (1) the integration of Air Force and Navy projects into a joint office, (2) the development of a family of missiles with a high degree of commonality, (3) the acquisition management and contracting strategies used throughout the project, and (4) methods used to maintain quality throughout the duration of the manufacturing phase. All of these elements clearly interact with each other, but it seems more useful to discuss each in turn, rather than to blend all four into a single chronological tale. This section describes only the highlights; additional information on many of the topics is contained in the appendixes, which are referenced throughout the text.

EVOLUTION OF THE JOINT PROJECT OFFICE

In 1973, the Joint Logistics Commanders signed a Memorandum of Agreement (MOA), which was subsequently promulgated as a joint regulation.[2] That document set forth principles of the joint project management concept and provided a foundation for the establishment of joint service project management offices. All of the Armed Services have promulgated joint as well as individual service project management documents. If properly operated, joint service projects can squeeze more out of research, development, and production budgets; simplify logistics support operations; and improve combat capability. They have also been strongly supported and encouraged by the OSD and the Congress.

The DSARC II decision memorandum of January 14, 1977, mandated the formation of a joint project office with the Navy as lead service and Capt. Walter M. Locke (who had managed the Navy cruise missile project since 1972) as the project manager.[3] The decision memorandum further directed the JCMPO to "maximize subsystem/component commonality and quantity buy, to utilize fully joint test and evaluation, to encourage subsystem/second-source competitive procurement, and to otherwise derive maximum benefit from the joint service management of several separable cruise missile programs."

In addition to procurement cost reductions through subsystem/component commonality between the cruise missile variants, joint testing was also desirable to lower cost and schedule risk by reducing the number of test vehicles, interchanging existing test data, and using common planning for future test projects. Implementation issues, such as how the JCMPO would be staffed, how funding would be transferred from the services, where the project office would be located, and which service would retain control over common subsystems developments (engine and guidance) within the JCMPO were left to the services to resolve.

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[1]Project complexity was largely due to the JCMPO's attempts to minimize schedule risk and cost growth through subsystem competitive dual sourcing.

[2]*Management of Multi-Service Systems/Projects/Programs*, AFSC/AFLC R-800-2/AMC R 70-59/NAVMATINST 5000.1A, July 1973

[3]Beginning on April 12, 1978, the JCMPO manager and deputy manager titles were changed to director and deputy director. The latter titles are used throughout the remainder of this report.

The Air Force and Navy were directed to submit jointly to the DDR&E within 45 days the plan for establishing the JCMPO and a set of project plans, schedules, and milestones for the respective cruise missile projects. However, for the next eight months the two services continued their own projects while negotiating a joint project organization that would be acceptable to both services and to the JCMPO. Principal issues were the location of the ALCM and GLCM offices, the budget control authority of the joint project director, the lead service for the engine and guidance systems procurement, the mechanism for consolidation of service funding, and other organizational and personnel related items. On March 25, 1977, the Acting Director of Defense Research and Engineering, Mr. Robert N. Parker, issued a second memorandum to the two services directing that: (a) the JCMPO Manager (Navy) and his Deputy Manager (Air Force) would be responsible for the overall cruise missile systems development process; (b) "Maximum commonality on subsystems, components and software, joint testing and evaluation, and quantity buy of common components will be carefully planned and implemented without degrading individual system performances"; (c) upon receipt from OSD, the Air Force was to transfer its entire program element fund for ALCM and GLCM, and the Navy its entire fund for SLCM to the JCMPO; and (d) the Air Force was designated the lead service for engine development and the Navy for guidance systems for all cruise missiles under the jurisdiction of the JCMPO. In addition, an Air Force Deputy Project Manager for (turbofan) Engine Development would be assigned and his office located at Wright Patterson AFB (Dayton, Ohio), while the office of the GLCM Deputy Project Manager and his staff would be collocated with the SLCM Project office to ensure close coordination. The services accepted most of those directions but continued to debate two items: the location of the GLCM office and the exact distribution of project control between the two services.

On September 30, 1977, the Under Secretary of Defense for Research and Engineering, Dr. William Perry, issued a third memorandum to the two services that resolved the remaining major organizational issues and established a clear organization framework and set of objectives for the joint office. Three elements of that memorandum deserve particular notice here. First, it reiterated the earlier mandates that the Air Force GLCM program office should be jointly located with the SLCM during the development phase and noted that at some future time each Air Force program (ALCM and GLCM) would be expected to return to Air Force management control (but not earlier than DSARC III). This set clear bounds on the range of JCMPO control over the programs and identified the need for a transition plan as the DSARC III date approached for each system.

Second, the memorandum directed that a formal ALCM competition take place between the Boeing-designed AGM-86B and the Convair-designed AGM-109 to determine which missile would be deployed on the B-52. At that time, four separate cruise missiles were to be under JCMPO management once its charter had been approved by the Air Force and Navy; the AGM-86B candidate ALCM (derived from the AGM-86A, or ALCM-A), the AGM-109 candidate ALCM (derived from the SLCM), the GLCM, and the SLCM (which included anti-ship and nuclear armed land-attack variants).[4] Dr. Perry also specified the authority and the general organization structure that the JCMPO would have. Simply stated, the ALCM flyoff was elevated to a matter "of highest national priority," and OSD would not allow service infighting to continue to impede the creation of the JCMPO or its subsequent operation.

Finally, the September 30 memorandum strengthened the joint management process by forming an Executive Committee (EXCOM) to provide programmatic and fiscal guidance.

[4]The conventionally armed land-attack SLCM was not considered a part of the SLCM program until 1978 and was first reported in the December 1979 SLCM SAR.

Under the general organizational structure outlined by Dr. Perry, the JCMPO reported: (a) directly to the Chief of Naval Material (CNM) for administrative matters and for execution of the Navy program management responsibilities; (b) through a coordination link to the Air Force Systems Command (AFSC) for reporting Air Force program management responsibilities; and (c) through an advisory link to the EXCOM.[5] The resulting organizational structure appears to put the JCMPO Director in the position of reporting to three different authorities. Admiral Locke was clearly *responsible* for management of the project, but the exact distribution of *authority* is less well defined. In retrospect, the EXCOM appears to have been a key element in the management scheme. To be successful, a joint office must have top-level support from the participating services and cooperation between them. This is particularly true in any project where the system under development is deemed important by one service, as the ALCM was for the Air Force. But even with such cooperation, the inevitable intra- and inter-service bureaucratic complexity of a joint project office makes necessary a consolidated reporting mechanism—namely a strong, high-level member of OSD to make the services come together and to adjudicate conflicts. In the JCMPO case, this role was performed by the EXCOM, chaired by Dr. Perry.

Comprising senior personnel from each service and from OSD,[6] the EXCOM provided a mechanism for resolving the inter-service disagreements and ensuring that the project received enough high-level attention to permit timely resolution of most problems. The first EXCOM meeting was held three weeks after the September 30 Perry memorandum; a total of 25 such meetings were held, the last in January 1981. The EXCOM was not a voting group, rather its purpose was to review and discuss in an attempt to establish a consensus. In the absence of a consensus, the chairman would make the necessary decisions but would report dissenting opinions to the Secretary of Defense. Normal channels remained open to the services to express dissent.

In practice, the EXCOM served several functions. One was to provide a periodic and structured forum for examining problem areas. The participants could work out mutually satisfactory solutions in a short time, avoiding many of the bureaucratic steps that would normally have been required. Most issues were rather quickly resolved, in part because of a good working relationship among the participants, and in part because of their knowledge that the chairman was willing to make a command decision on disputes that were dragging on too long. A second important point was that the EXCOM members had enough authority to permit timely resolution of problems. The several elements of the cruise missile project were being developed, integrated, and tested on a tight schedule, and in those conditions it was inevitable that funding shortages would appear from time to time. EXCOM members usually resolved such shortages.

The EXCOM associated with the cruise missile project was discontinued after its final meeting on January 8, 1981. This was partly a result of the new management team in OSD who wanted to give more project control to the individual services. Thereafter, the Air Force continued to monitor the project through its regular process, which included a formal, high-

[5]In April, 1978, the link to the AFSC was changed from "reporting and coordination" to "command" to more formally recognize Air Force program control, and that arrangement remains to date.

[6]The original members included the Under Secretary of Defense for Research and Engineering (who chaired the committee), the Assistant Secretary of the Navy(RE&S), the Assistant Secretary of the Air Force(RD&L), the Vice Chief of Naval Operations, the Air Force Vice Chief of Staff, the Assistant Secretary of Defense(PA&E), and the Assistant Secretary of Defense(Comptroller). After the first meeting, the Chief of Naval Operations and the Commander of the Air Force Systems Command were added as permanent members.

level review each calendar quarter.[7] The Navy organized a Cruise Missile Steering Group within the office of the Chief of Naval Operations (chaired by the Director of the Office of Naval Warfare), but that committee was not sufficiently powerful to resolve important policy issues. Beyond that time, the director of the JCMPO had no effective formal mechanism for resolving issues between the two services.

This change in organization had some predictable consequences. Shortly after the discontinuation of the EXCOM, the Air Force renewed its efforts to withdraw GLCM and the Medium Range Air to Surface Missile (MRASM) from JCMPO management. Another effect was a psychological one in the minds of some members of the JCMPO and associated service officials. While the EXCOM was in operation, the cruise missile project had a recognized level of importance by the OSD. After the EXCOM was discontinued, at least some personnel took this action to mean in part that the level of OSD support for the cruise missile project had diminished. Although it was impossible to quantify, this factor undoubtedly had some effect on the cruise missile project.

Joint Office Management Tasks and Organization

When it was formed, the JCMPO faced an unusual set of management tasks. In addition to the problems of integrating the projects of the two services, another source of special difficulty was that the project consisted of multiple contractors reporting directly to the JCMPO, with the project office acting as an overall system manager. Part of this arrangement was inherited when the project office was formed, with separate sources for engine and guidance subsystems that were supplied as government furnished equipment (GFE) to the ALCM and GLCM/SLCM developers. Over time, the list of associate contractors[8] grew through the practice of breakouts and the introduction of second sources for most of the major subsystems. The project office had to manage the introduction of the second source suppliers, design and monitor techniques for transferring technology from the subsystem developer to the second source, ensure that the various system components were technically integrated, and provide a configuration control process to ensure a maximum degree of commonality among the missile variants. Furthermore, they had to design and manage an integrated test program that made maximum use of inter-system testing commonality to minimize the total number of test flights conducted. Finally, in 1981, the JCMPO started negotiating a dual-source arrangement for the airframe and guidance elements of the flight vehicle[9] for the entire SLCM/GLCM family.

By early in 1978, the JCMPO organization had reached a form that was to endure, with only minor changes, for two and a half years, and by the middle of 1978 the office was almost fully staffed. The initial organization, shown on Fig. 2, consisted of a directorate for each of the three missile variants (ALCM, GLCM, and SLCM) and one for each of the two major subsystems (propulsion and guidance). These were supported by three technical groups (System Engineering, Test & Evaluation, and Mission Planning) and the usual staff support functions. The staff was about equally divided between Air Force and Navy personnel, but the military-civilian distribution was quite different for the two services. The Navy staff

[7]The process involves a standardized review format and includes participation by the Commander, Air Force Systems Command, the Vice Chief of Staff, and the Secretary of the Air Force.

[8]Throughout this report we will adopt the JCMPO convention of designating Boeing, GD/C and MDAC "prime contractors" and the other firms that contracted directly to the JCMPO as "associate contractors."

[9]This combination of system elements constituted the "All Up Round" (AUR), which is discussed in additional detail below.

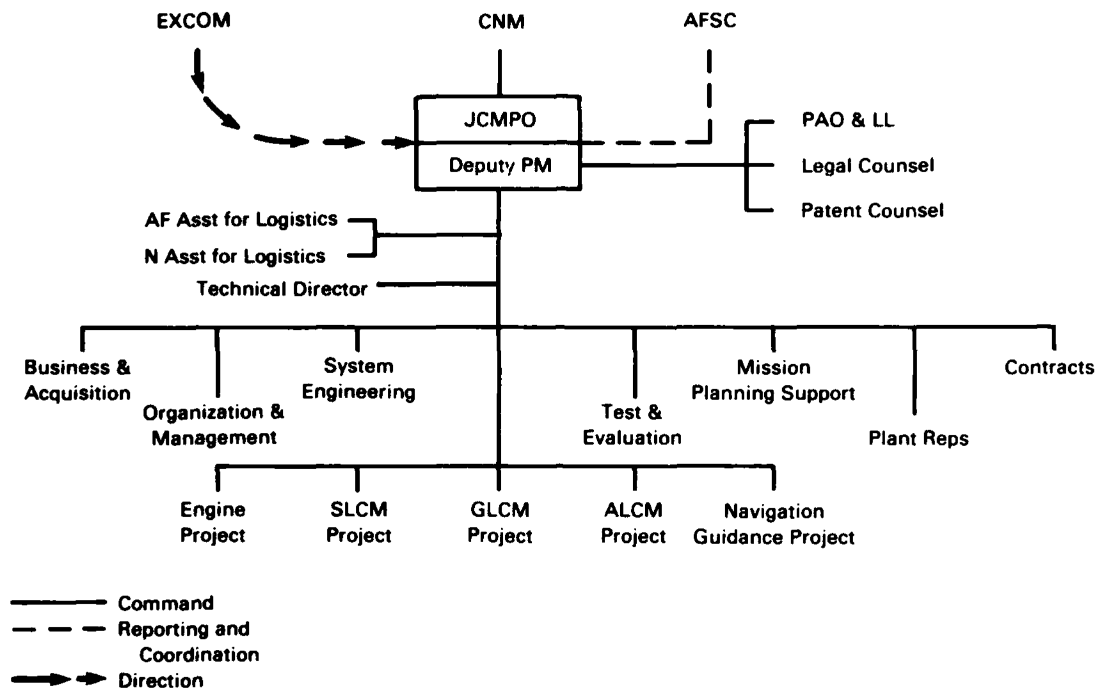

Fig. 2—Initial JCMPO organization

consisted of about 40 uniformed personnel and about 150 civilians, and the Air Force staff was distributed almost exactly the reverse. The Naval Air Systems Command and other related Navy organizations were located in the Washington, D.C., area and civilian personnel could easily be transferred to the JCMPO. Most of the Air Force staff with systems management experience were at Wright-Patterson AFB in Dayton, Ohio, and the difficulty of transferring civilian personnel for long tours of duty made it necessary to rely mostly on military personnel.

While quality of leadership is always important, a joint project appears to place special demands on the project director in order to overcome the institutional hurdles that will probably be present, and to instill a sense of unity within the project. As stated by the Defense Systems Management College:

> One of the joint program director's greatest challenges is creating an *esprit de corps* within the program office. There are bound to arise situations in which the Services' interests conflict. Success of the program then depends on having program management staff personnel who are committed to resolving the problems, rather than provoking confrontations. Representatives from the participating Services must be expected to guard their Services' interests; that is why they are assigned to the program office. But their attitude and approach must be dedicated to success of the program.[10]

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[10]*Management of Joint Service Programs*, Defense Systems Management College, Fort Belvoir, Va., March 1980, p. 6-6.

Similarly, selection of the Deputy Program Manager(s) and other key staff members is important to ensure a good working relationship and minimize the distraction of inter-service rivalry.

Transition to the joint project in the JCMPO case required extensive relocation of Air Force offices and personnel, and Air Force adjustments to the Navy's operating procedures. It also required establishing workable chains of communication, obtaining concurrence on common terminology/reporting formats, establishing budgets and schedules, and reconciling service differences on logistic and system support philosophy. Considerable differences in Air Force and Navy maintenance procedures made this last factor especially difficult to solve.

Manpower issues associated with critical vacancies, the stability of key personnel, and personnel training levels also affected the JCMPO management. Organizational factors that affected the JCMPO included the initial lack of a centralized configuration control board, differences in Air Force and Navy philosophies on funding control (which slowed funding obligations from the individual services), and delays in consolidating the framework because of differences between the JCMPO and the Air Force on responsibilities, site location, and representation.

One important characteristic of the JCMPO organization was the stability of staff positions. Students of military systems acquisition management have long recognized that efficiency has been hampered by a high turnover rate in project office positions, and senior OSD officials have periodically called for slower turnover in such positions. A review of project director tenure in major acquisition project offices[11] showed some improvement over the past two decades, but by the late 1970s average tenure was only 30 months. The JCMPO is a striking exception to that practice. Captain (now Rear Admiral) Walter M. Locke was appointed to head the Navy cruise missile office in 1972, was designated to head the JCMPO when it was formed in 1977, and remained in that office until mid-1982, thus completing an unbroken tour of almost a decade in that position. Furthermore, a large number of the important civilian and military personnel who joined the JCMPO during its formative months in 1977 remained throughout the next five years, thus providing continuity of experience through the critical years of the project. Although it is not measurable in any direct way, this continuity of personnel must surely have contributed to management effectiveness.

The separation of the Air Force staff from their traditional support staff (located at Wright-Patterson AFB in Dayton, Ohio) was a source of continuing difficulty. This was especially true for the engine project, because that project had been managed for the preceding several years by the Joint Engine Project Office (JEPO) at Wright-Patterson AFB, and it took several years to develop a staff of propulsion experts in the JCMPO that could handle most of the propulsion development and system interface problems without a considerable amount of travel and message traffic. The GLCM project suffered similar difficulties, drawing on a staff of over 20 specialists at WPAFB while maintaining only two or three technical people at JCMPO. Again, an unusual amount of travel and message traffic was required.

In July 1980, following transition of the ALCM program to Air Force management at ASD at Wright Patterson AFB, the complete JCMPO was reorganized along a matrix style, as shown in Fig. 3, to account for a loss of nearly half of the Air Force billets that returned to ASD with the FY80 and FY81 production contracts, and the follow-on test and evaluation program. The move to a matrix organization also paralleled a similar reorganization at ASD. Both efforts were aimed at conserving manpower and providing cross-feed between similar

[11]Dews et al., *Acquisition Policy Effectiveness.*

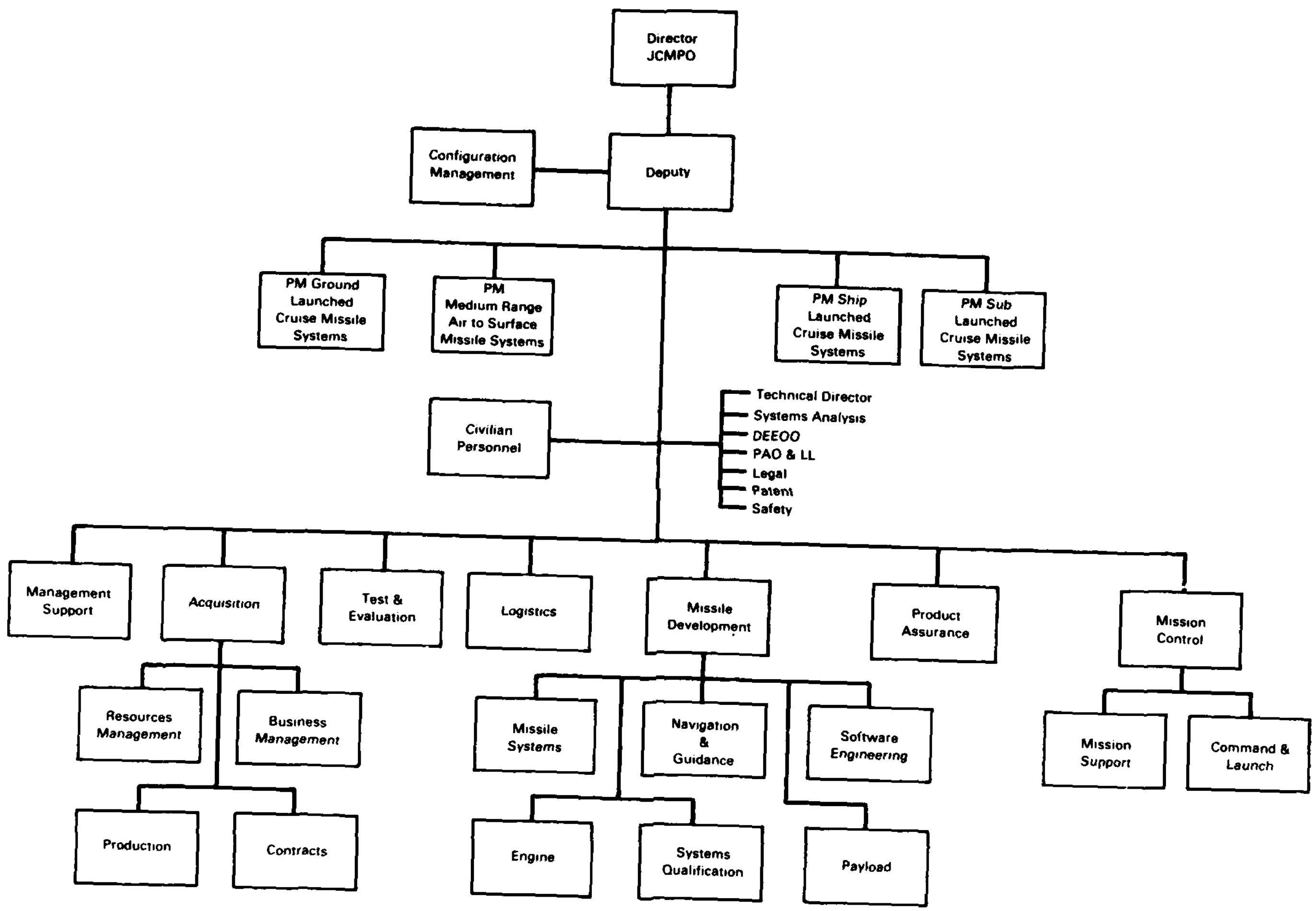

Fig. 3—July 1980 JCMPO organization

platforms with common problem areas. The main effects of this change were to split the Sea Launched project into Submarine Launched and Ship Launched projects, and to establish four new support groups: Logistics, Missile Development, Product Assurance, and Mission Control. Staff for these groups was drawn largely from the three previous missile directorates, with the total staff size remaining essentially unchanged. Under the new (matrix) organizational structure, however, the technical and support resources could be more efficiently utilized across the different missile projects. For example, Test and Evaluation (T&E), Logistics, and Missile Engineering staffs previously located in the SLCM project were transferred to the existing T&E Directorate, and the newly formed Logistics and Missile Development Directorates respectively. Similarly, Configuration Management, Logistics, and T&E groups internal to the SLCM and GLCM Projects were transferred to the Configuration Management, Logistics, and T&E Directorates respectively. Also, the Manufacturing/Production Control group that had been housed under the Acquisition Directorate became a separate Production Division, and a new Product Assurance Directorate was established to manage quality and reliability issues.

Several important functional changes accompanied that reorganization. Perhaps the most important was the establishment of a Systems Project Officers Council (SPOC), composed of the directors of the four major missile systems (consisting at that time of the GLCM, ship- and sub-launched SLCM, and the newly introduced MRASM). The SPOC members were given the authority to allocate resources for all technical matters in their individual projects according to outstanding tasks and their priorities, together with appropriate inputs from the Acquisition Directorate and the affected matrix groups. With this authority, the SPOC could perform functions previously requiring the personal attention of the Director. Issues the SPOC could not resolve were presented to the Director for decision. Another change was the creation of a special office for configuration control of all missile variants. Through this office, the JCMPO now serves as the master configuration control body to ensure that variations among the various cruise missile configurations were kept to a minimum.

Another important change was in the management of the cruise missile engine program. Under earlier organizational structures the engine, along with guidance and control, had warranted major directorate status. By mid-1980 the bulk of the development work in each subsystem had been completed, and technical management of both was placed under the Missile Development Directorate. At the same time, the engine management function was moved from the JEPO at Wright Patterson AFB to the JCMPO. Only modest changes have occurred in the project office structure since the mid-1980 reorganization.

In November 1981, an Acquisition Strategy Board was organized within the JCMPO to systematically examine alternatives and to select an appropriate acquisition strategy for the various system elements. The board met approximately twice a month, with each meeting typically devoted to review of one particular subsystem or component. Consideration was given to such issues as whether to break out the element for procurement directly by the JCMPO, introduction of a second source, and application of multi-year procurement.

Additional details on JCMPO organization and operating procedures are contained in Appendix A.

Interactions with Other Agencies

In addition to interacting with the Air Force and Navy, and with multiple contractors, the JCMPO had a further management complication through having to perform critical

testing[12] and obtain critical data from other defense department and intelligence community sources. The guidance system used in the land-attack cruise missiles relies on various types of terrain data for the over-land portions of the missile flight path.[13] Such data are supplied by the Defense Mapping Agency (DMA) to specifications they developed with the concurrence of operational users and the JCMPO. The quality and scope of such data, and the resulting interactions among the JCMPO, operational users, DMA, and the contractors are essential to the success of the cruise missile project and other projects (i.e., Pershing II) now and in the future. Furthermore, the cost of data preparation is not an insignificant element of total project cost. Therefore, the interactions between JCMPO and DMA deserve a brief summary.

Before the imposition of any requirements from the cruise missiles project, the DMA possessed the technical capability (equipment and techniques) to produce digital data for terrain following and TERCOM. Although little was needed in terms of development, a considerable increase in rate production techniques was required to support the cruise missile project. DMA had been producing high quality digital elevation data for developmental flight testing in support of the TERCOM program since the early 1970s. This basic product was used for the TERCOM Aided Inertial Navigation test flights that were completed in March 1973, the contractor TERCOM test flights in 1973-1974, and the competitive flyoff for the Navy cruise missile guidance system that concluded in October 1975.

As the size and complexity of the project grew, the DMA established a full time cruise missile project manager to monitor and direct overall project support; formed a high-level cruise missile steering group composed of DMA senior staff to focus on management, project progress, and problems; and allocated special security clearances to contractor engineering personnel to assure their total understanding of the DMA data.

Initially, the principal role played by the DMA in the TERCOM guidance updating system was in the generation of the input terrain elevation data to the map making process. On June 30, 1977, the Navy cruise missile project office transmitted a letter to the DMA establishing requirements for the data base to support the cruise missile TERCOM and terrain following programs.

The technical approach used by Boeing and MDAC for TERCOM reference map size and selection were considerably different, however, and if allowed to continue could have caused the DMA to produce duplicate TERCOM reference scenes in any joint use (ALCM-SLCM) operational area. The diversity of technical requirements also caused confusion in the ALCM user community, which resulted in the Joint Strategic Target Planning Staff (JSTPS) and the Strategic Air Command (SAC) also determining their own technical needs for TERCOM. Because of the potential effect on cost and output and because of the different contractor approaches for implementing TERCOM, the DMA requested that the newly formed JCMPO establish a single set of technical TERCOM specifications.

On November 2, 1978, the JCMPO transmitted specifications and requirements for the cruise missiles data base to the DMA. The intent was to revise and expand the guidelines previously provided to the DMA by letter of June 30, 1977, for the generation of data bases required by land-attack cruise missiles that utilize terrain following and TERCOM. In addition to specifying the need for the terrain following and TERCOM data bases, that letter provided information and guidance on the structure of the data bases and the proper use of each in planning cruise missile missions. The guidance provided was specific to the degree

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[12]This was especially true for the cruise missile survivability test program, which had to be coordinated across service and agency lines. See Appendix C for a more detailed description of that program.

[13]See Appendix B for a more detailed description of the data needs and how those data are prepared.

necessary to avoid duplicative work by the DMA, yet left enough flexibility to allow mission planners to meet individual requirements of the ALCM, GLCM, and SLCM programs.

The existing DMA management organization and normal internal coordination between Requirements and Production Directorates were used to support the cruise missile project. The DMA Requirements Directive defined the requirements for TERCOM reference maps based upon input from the JCMPO, and later from the operational commands, and assigned them for production. Ad hoc working groups were formed for particular problems. User interaction has been excellent throughout the ALCM program, with daily to weekly contact at the action officer level and monthly briefings conducted for the senior staff between the DMA and the JSTPS/SAC. Contact with GLCM and SLCM Theatre users and service monitors was initially minimal but has increased to parallel the JSTPS/SAC interaction as the initial operational capability (IOC) dates for the individual missiles get closer.

Although the interaction process between the DMA and the JCMPO has at times been strained, in part because of perceived roles of the two organizations, both Directors realized that a positive and effective relationship was critical to the success of the cruise missile project. Production priorities were resolved directly between the DMA and operational commands. Given that the TERCOM reference scene production schedule is currently meeting or exceeding the goal, it is obvious that whatever the nature of this organizational friction, it has not greatly affected the cruise missile project. In summary, to quote Major General William L. Nicholson, the former Director of the DMA:[14]

> Our commitment to the cruise missiles results in the most critical and demanding production assignments facing [the] DMA. The program's priority and the extremely complex and time-sensitive issues of technology, requirements, resources, and production all demand that we [the DMA] give the cruise missile program the highest level of attention possible.

CRUISE MISSILE PROJECT COMMONALITY

The idea of a high degree of commonality among a family of missiles has been a major theme of the cruise missile project since the first attempts to merge the Air Force and Navy projects in 1973. Commonality offers the potential of considerable reductions in both development and procurement cost, but it has traditionally been very hard to achieve and maintain because of the desire to tailor each system to achieve maximum performance and to satisfy the unique user requirements of each service.

Cruise Missile Variant Weapon System Description

As of mid-1982, the family of missiles included the ALCM, GLCM, MRASM, and SLCM weapon systems. The GLCM and MRASM are derivatives of the Tomahawk (SLCM). A high degree of commonality exists even between the ALCM and these other systems, in terms of the engine, guidance system, and missile radar altimeter (MRA). The ALCM weapon system consists of the ALCM, support systems, and the B-52.[15] Only the ALCM development was under the direction of the JCMPO. The B-52 and support systems were under the purview of the Strategic Systems Program Office at ASD and are not discussed here. The ALCM

[14]"DMA—The Cruise Missile's Silent Partner," *Air Force Magazine*, Volume 63, Number 4, April 1980, p. 62.
[15]The B-1B is also planned to be an ALCM carrier.

(AGM-86B) system consists of three major subsystems: airframe, engine, and guidance. The airframe and guidance software concepts are a direct outgrowth of the AGM-86A Advanced Development missile, which in turn was an outgrowth of the SCAD. Basically the engine, guidance set, flight control and fin/wing extension system are improved or qualified versions of the equipment used in the AGM-86A. The ALCM utilizes a larger, nuclear hardened computer and a 15 state Kalman filter in lieu of the 11 state filter previously used. The length was changed from 168 in. to 249 in. to provide for longer range.

The Tomahawk integrated weapon system contains four major subsystems, as shown in Fig. 4, including the SLCM All-Up-Round, the Launcher or the Launch Platform/Weapon Control Subsystem, the Support Subsystem, and the Mission Planning Subsystem.

The SLCM AUR consists of the airframe, F107 sustainer engine, booster, and guidance system contained in a canister or capsule for protection during storage, handling, loading, and launching. A steel capsule is used for submarine launched versions and an aluminum canister for ship launched versions. There are three versions of the SLCM under development: nuclear-armed land-attack, conventionally armed land-attack, and anti-ship. These are all based on the Tomahawk airframe, with different guidance subsystems or warheads.

The GLCM weapon system is composed of six subsystems, as shown in Fig. 5; three are air transportable tactical subsystems and three are support systems. The three tactical subsystems are the missile, the Transporter-Erector Launcher, and the Launch Control Center. The three support subsystems are operations and basing, logistics support, and mission planning.

The GLCM missile subsystem consists of the airframe, F107 sustainer engine, CMGS, payload, booster motor, and canister. The missile, designated BGM-109G, is derived from and is nearly identical to the SLCM, with minimum adaptation to accommodate the GLCM missions. Only the GLCM warhead and some related hardware are different from that of the land-attack nuclear-armed SLCM.

The MRASM is an air launched tactical cruise missile derived from the SLCM design. Because the very existence of the MRASM may result from the adaptability of the basic SLCM design, it deserves a more extensive discussion. Its conceptual origin is based upon a series of Air Force and Navy studies, including the Air Force Strike Options Comparison Study and the Advanced Conventional Standoff Missile (ACSM) Study (1975-1976 and 1978-1979 respectively), and the Navy Tactical Operations Study (1977-1978). Those studies led to the Air Force ACSM project at Eglin AFB and the Navy Supersonic Tactical Cruise Missile (STCM) project at the Naval Weapons Center.

The Navy initially approached the Congress for STCM funding in FY79, and the Air Force was at the time approaching Congress for their second year of funding for ACSM development. Both requests were rejected, and Congress directed the Air Force and Navy to come back the following year (1980) with a more plausible plan for standoff missile development. The following year, Congress told the Navy that only a single, joint project with the Air Force would be acceptable. Given the Air Force's need for a much greater ordnance carrying capability than could be provided by the STCM, the Navy had to either adopt a subsonic carrier or lose its chance for an operational weapon system. (The Air Force by then had chosen a low-cost derivative concept of a subsonic cruise missile for its ACSM development missile and had issued a competitive RFP for advanced development work.)

The two services then attempted to write a Joint Services Operational Requirement. The first draft would have necessitated a vehicle similar to the ACSM and STCM for the Air Force and Navy respectively. Although forced into a joint project, the Navy at that time had not given up hope for the development of the STCM. The Navy operational command finally

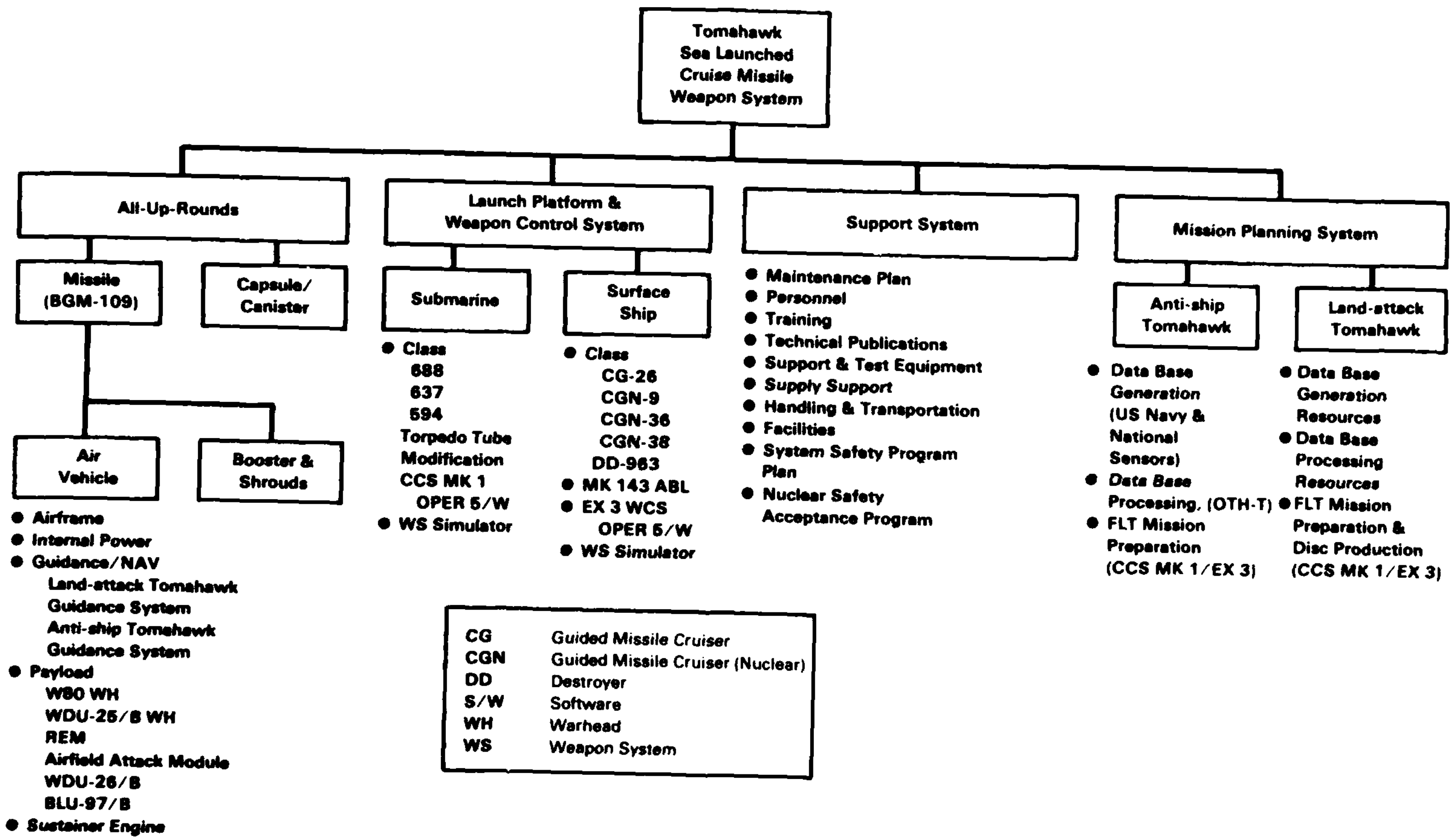

Fig. 4—Tomahawk weapon system

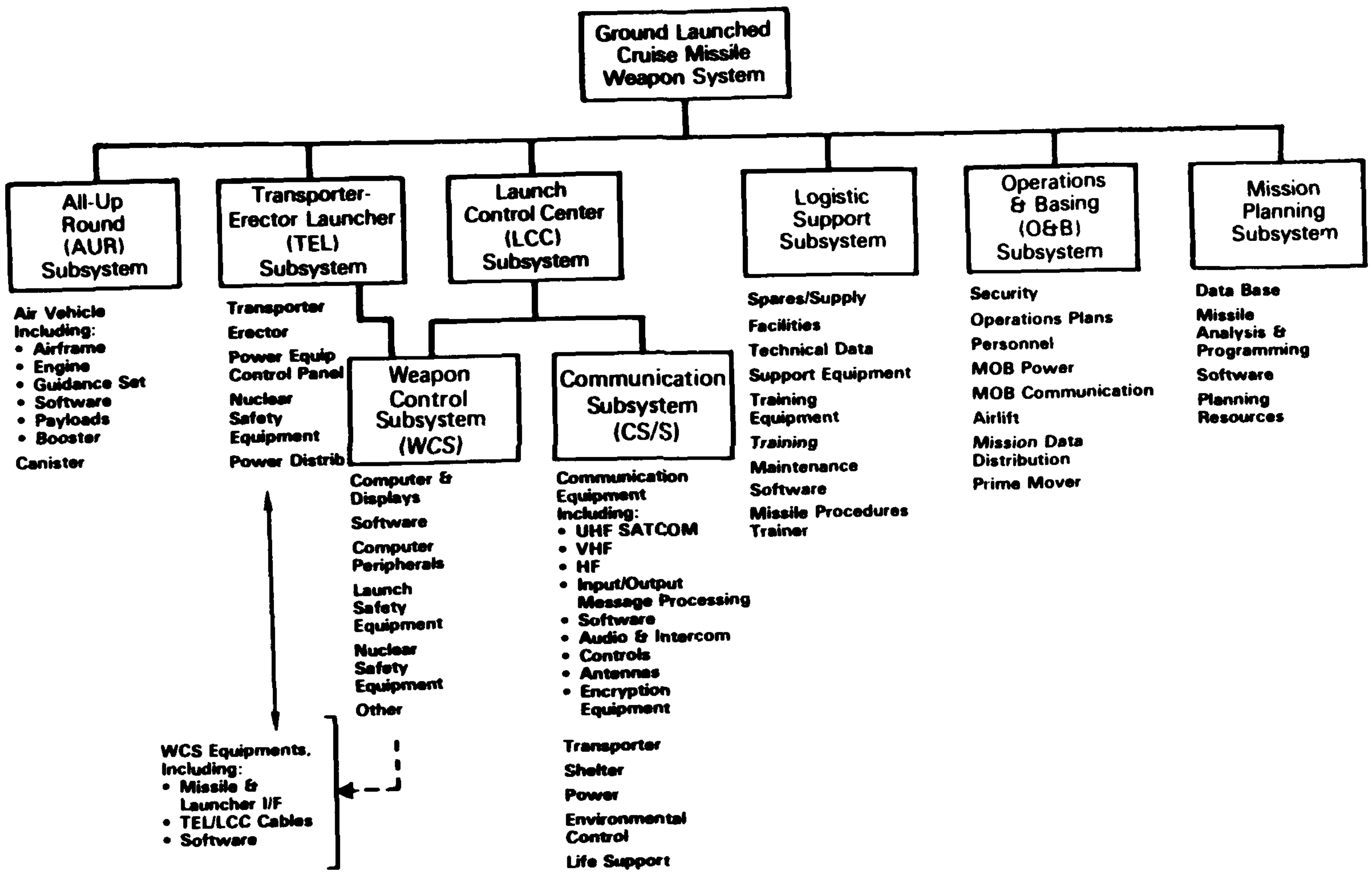

Fig. 5—Ground launched cruise missile weapon system

realized that although it still believed that a supersonic missile was the best choice (because of a perceived improvement in penetration capability), the only way to satisfy the Air Force and the Congress was to use the subsonic cruise missile derivative, ACSM. That plus the successful flight of the General Dynamics Tomahawk Airfield Attack Missile (TAAM) on May 26, 1978, was the start of the conventional standoff cruise missile project.

The Air Force initially organized the ACSM as a classical acquisition program, including a competitive advanced development phase. The potentially long acquisition cycle of six to seven years, which might have stretched to 10 years, combined with OSD concern for the long acquisition time-frames in general for DoD weapon systems, created tension between the Air Force and OSD on the development of the missile system. If a derivative based upon the Tomahawk was used, however, the development cycle and deployment time could be reduced, because considerable missile development had already occurred.

Potential problems with the Air Force-sponsored and British-developed JP-233 flyover runway attack munition, the fact that the ACSM (now termed MRASM) could potentially achieve an early IOC if derived from the Tomahawk, and the support of Dr. Perry contributed to the birth of the MRASM program. In his March 7, 1980, memorandum, Dr. Perry stated:

> I would like to see a development program to adapt the existing (Tomahawk) cruise missile to meet joint Navy-Air Force requirements for a tactical medium-range air-to-surface missile (MRASM). This new development program should be managed by the JCMPO whose first task will be to determine the baseline design most nearly compatible with the requirements of the Air Force and the Navy, while making maximum use of the hardware already developed and tested.

Shortly after the initiation of the MRASM program, the United States withdrew funding support from the JP-233, leaving MRASM as the only airfield attack program with funds.

The MRASM weapon system includes four subsystems, as shown in Fig. 6: the missile, carrier aircraft and equipment, support equipment, and mission planning.

The Air Force version of MRASM, the AGM-109H, is 232 in. long and weighs approximately 3000 lb. The missile will incorporate new guidance, engine, and payload elements while retaining the basic airframe structural/aerodynamic design approach used for other Tomahawk missiles. The guidance system will consist of TERCOM, digital processors, a MRA, and a Digital Scene Matching Area Correlator (DSMAC) common to those on the conventionally armed land-attack SLCM, together with a lower cost inertial sensor assembly (ISA). The designated engine is the TCAE J-402-370-IT turbojet (an adaptation of the Harpoon engine), although the WIC F107 can be accepted because of reverse commonality considerations. (A discussion of reverse commonality designing between the MRASM and Tomahawk is given later in this section.) The primary payload for the AGM-109H will be either the STABO or the Boosted Kinetic Energy Penetrator, both of which are under development.

The Navy version of MRASM, the AGM-109L, is 192 in. long and weighs approximately 2200 lb. It retains the basic airframe structure/aerodynamic design used for the AGM-109H and other Tomahawk missiles but will utilize wings swept at 28° rather than the same wings fully extended (straight) as on the other Tomahawk variants. In addition to the AGM-109H guidance elements, the AGM-109L will incorporate an imaging infrared (IIR) seeker and command/video data link. The AGM-109L payload will be the WDU-18/D unitary, high explosive warhead developed for the Harpoon anti-ship missile.

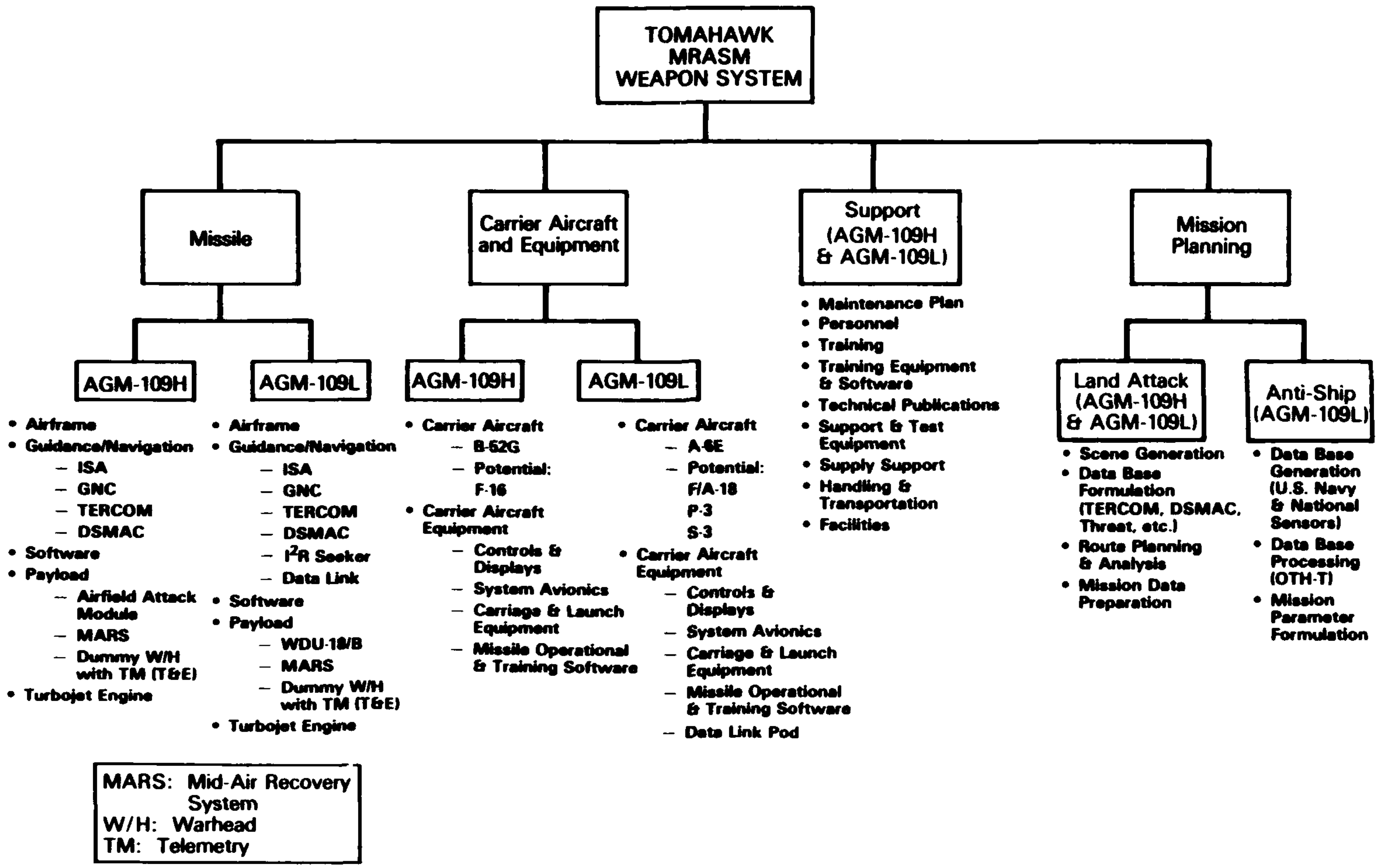

Fig. 6—Tomahawk MRASM weapon system

Missile Commonality

A representation of the commonality present for major systems between cruise missile variants is given in Table 1. The degree of commonality between the ALCM and the GLCM and nuclear armed land-attack SLCM is approximately 15 percent, 75 percent, 85 percent, and 100 percent for the airframe, guidance, engine, and MRA respectively.[16] Additional cost savings through commonality will also come from:

- A common missile system test set;
- Highly common airframes between SLCM variants;
- The SLCM airframe design for the GLCM;
- A derivative of the SLCM airframe design for both MRASM variants;
- A ship-launched SLCM platform Armor Box Launcher (ABL) that can accommodate the Harpoon, and a Vertical Launch System that is common with the Standard Missile;
- Derivatives of the Harpoon guidance for the anti-ship SLCM, and Harpoon J402 engine for both MRASM variants;
- A common capsule for submarine-launched SLCMs and canister for sea-launched SLCMs;
- A common weapon control system (CWCS) for ship and ground-launched missiles;
- A common nuclear warhead for the ALCM and nuclear-armed land-attack SLCM;
- A common booster for the GLCM and SLCM;
- A common mission planning system for land-attack missile variants used in theater applications.

An early commonality consideration that affected Tomahawk missile design and performance involved the sustainer engine and wing area used. Originally, it was envisioned that the F107 and J402 engines, and a wing area of nine and 12 ft^2 would be used for the nuclear-armed land-attack and anti-ship SLCM variants respectively. Captain Locke made the decision to standardize on the most conservative combination for both vehicles: the F107 engine and the 12 ft^2 wing area. Consequently, that combination is used on the GLCM and SLCM variants today as part of the common aft end.

MRASM Reverse Commonality

The commonality discussed above was mainly achieved by imposing design constraints on each new variant of the basic SLCM configuration. However, each variant has some unique design features. In the MRASM project, some of the unique features that had to be incorporated into the missile design were configured so that they could be later incorporated into the GLCM and, particularly, the SLCM to reduce production and Operations and Support (O&S) cost, and improve reliability. This process has been dubbed "reverse commonality" because earlier designs are changed to correspond to later variants.

Air Force and Navy mission requirements for MRASM have resulted in several configuration changes to the basic Tomahawk airframe. These include relocation of the guidance system to the aft body, and an aft body structural revision for accessibility and increased

[16]The ALCM is also common with the anti-ship and conventionally armed land-attack SLCMs to the same degree as above, except for the guidance system. There the ALCM is 60 percent common with the conventionally armed land-attack SLCM but 0 percent common with the anti-ship SLCM.

Table 1

CRUISE MISSILE COMMONALITY

Missile	Airframe	Guidance System	Engine	MRA(a)	CWCS(b)	BOOSTER
ALCM	Boeing	CMGS	F107	Yes	NA	NA
GLCM	GD/C	CMGS	F107	Yes	Yes	Yes
SLCM(c)						
A/S	GD/C	A/S(d)	F107	Yes	Yes(e)	Yes
LA-C	GD/C	CMGS(f)	F107	Yes	Yes(e)	Yes
LA-N	GD/C	CMGS	F107	Yes	Yes(e)	Yes
MRASM						
Air Force	GD/C	LC(g)	J402(h)	Yes	NA	NA
Navy	GD/C	LC(i)	J402(h)	Yes	NA	NA

NA = not applicable.
a: Honeywell or Kolsman design.
b: Common Weapon Control System (fire control).
c: A/S = anti-ship
LA-C = land-attack, conventionally armed
LA-N = land-attack, nuclear armed.
d: Anti-ship guidance system; derivative of Harpoon guidance system.
e: Ship-launched platform only.
f: CMGS with DSMAC for terminal guidance.
g: Low cost; includes ISA and DSMAC for terminal guidance.
h: Derivative of Teledyne CAE J402 Harpoon engine.
i: Low cost; includes ISA; and DSMAC and IIR for terminal guidance.

packaging volume. One result of this redesign activity for MRASM has been the development of a potentially common aft end for use on both anti-ship and conventionally armed land-attack SLCMs. The aft body and tailcone of the MRASM are cast and of a different (internal) design than their machined Tomahawk counterparts. These cast body sections are smaller and less complex than those used by the ALCM, so assembly times should be reduced and test procedures simplified. If utilized in future SLCM production, this is expected to lead to enhanced producibility, assembly, and maintainability, as well as a slight reduction in production cost (with no expected increase in SLCM development cost).

Several other MRASM features may be incorporated into the SLCM, including: a common aft-end interface; producibility improvements applicable to the midbody, aft body, and

tail cone; and interface compatibility for launch platform or payload peculiar hardware. To accommodate this potential reverse commonality, several ground rules were used in the MRASM design, including structural compatibility with the submarine and ship-launch environments and provisions for forward fuel location.

One result of incorporating these MRASM design characteristics into the SLCM would be to increase testability through the addition of a data bus, dry wiring, fault isolation, and a power switching antenna. These modifications would improve accessibility and fault isolation of important components, and reduce missile repair time.

Vehicle and Systems Integration

The technical integration task in the cruise missile project consisted of two somewhat different activities. One involved integrating the various subsystems within the air vehicle (vehicle integration), and the other involved integrating the flight vehicle with the launch platform and mission control module (system integration). The organization of these functions was further complicated by differences between the organization of the Navy and Air Force missile projects.

In the Air Force SCAD and ALCM programs, Boeing, the prime contractor, performed both vehicle integration and system integration. The ALCM/launch platform integration was aided by the fact that it was limited to two launch platforms (B-1 and B-52) during its design and development phase. Given Boeing's experience in developing the SRAM, its earlier development of the B-52, and the resulting integration of those two systems, ALCM/B-52 system integration proceeded smoothly, although the magnitude of the process was underestimated.

In the Navy SLCM project, responsibility for both vehicle and system integration was more distributed. Air vehicle and guidance system integration were assigned to GD/C and MDAC, respectively throughout the development phase. Integration proceeded incrementally throughout the design phase, with several of the early SLCM flight tests directed toward evaluating vehicle subsystem integration. For example, from March 1976 through January 1977 Tomahawk flights progressed from an integration of the missile/J402 engine/land-attack guidance, to the substitution of the F107 engine and implementation of TERCOM updates, to the addition of terrain following, and finally to the addition of the Scene Matching Area Correlator. Given these and a successful Tomahawk anti-ship test with Over-The-Horizon search capability in December 1976, anti-ship and land-attack Tomahawk vehicle integration were at an advanced stage by the DSARC II date.

Because of the variety of potential launch platforms (submarine, surface ship, ground and aircraft), it was not practical to give full system integration responsibility to a single contractor. In the SLCM case, the Navy retained a large portion of the systems integration function throughout the project.[17] A principal difficulty with that approach, however, was that the JCMPO was not adequately staffed to perform the function. Because of personnel shortages, individuals were often required to take on a system integration responsibility along with other designated duties. This, together with the large number of system elements furnished through JCMPO as GFE to the integrating contractors, further stretched the ability of the JCMPO to perform the full set of management tasks. Cause-effect relationships cannot be clearly defined, but inadequate staffing, caused by difficulty in obtaining and

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[17]In the GLCM program, the use of a single launch platform somewhat simplified the system integration task.

filling military and civilian billets, was apparently a major problem throughout the later phases of the cruise missiles project.

An example of the kind of problems that can arise is found in the SLCM project. The missile was originally designed for horizontal launch from a submarine, with a corresponding shock environment. To accommodate the shock environment on the submarine, a steel capsule was used for missile storage and launch purposes. However, some additional form of shock isolation may be needed for ship-launched missiles, particularly those that may be deployed in the vertical launch mode on battleships, where there is a different shock environment when the large guns are fired. Consequently, the variety of anticipated sea-launched SLCM deployments represents a considerable system integration challenge.

The mechanism that evolved to handle both vehicle and system integration tasks was to establish a number of technical interface working groups. These consist mainly of technical people from the various firms and service activities involved in a particular interface, each group monitored (and sometimes chaired) by a member of the JCMPO. Memoranda of Agreements would be drafted to define the working relationships and the responsibilities of each party, and the working groups then conducted the detail negotiations and design decisions necessary for technical integration of the system elements. Usually the JCMPO member took a passive role in the discussions, becoming an active participant only when necessary to resolve a conflict or to ensure that a design decision was consistent with overall design policy. The latter role was particularly important regarding issues of commonality among the several missile variants.

Although a designated Systems Engineering group existed within the JCMPO organization from November 1977 through April 1979, that group was primarily involved in the development of cruise missile CWCS, and not in the systems integration function. Before the July 1980 matrix reorganization, missile subsystem and missile/launch platform systems integration within the JCMPO was performed through the individual missile project groups. The extensive progress previously made in the SLCM project and the high degree of commonality between the SLCM and GLCM minimized the vehicle integration necessary for the GLCM. Following the July 1980 reorganization, vehicle integration was placed within the newly created Missile Development Directorate, and systems integration remained with the individual missile Projects within the JCMPO.

Configuration Management

Configuration management has been implemented for all GLCM, MRASM, and SLCM contractors per NAVMATINST 4130.1A. Technical documentation has been established for GLCM and SLCM missiles and launch platforms. A production baseline was established for the FY80 and subsequent production missiles, and formal change control procedures were established per Mil. Std. 480A for all hardware and software engineering documentation. Allocated baseline control was established during Full Scale Engineering Development. Configuration test baselines have been established for Developmental/Operational Testing (DT/OT) and Operational Evaluation. Test baselines are controlled to the piece part level, and include hardware and software configurations. Finally, production baselines have been established for all GLCM and SLCM missiles beginning in FY80. These production baselines include hardware and software detail part identification.

The JCMPO change control to baselines is conducted through formal configuration procedures using a Configuration Control Board including the Joint Configuration Control Board (JCCB) for Tomahawk and ALCM change control interaction. The Tomahawk configuration

control organization chart, shown in Fig. 7, depicts the change board relationships. NAVPRO, AFPRO, and DCASPRO organizations at contractor facilities implement change control and forward all Class I Engineering Change Proposals (ECP) to the JCMPO for disposition. In addition, MOAs between ASD, the Naval Sea Systems Command, the Naval Electronics Command, field activities, and the JCMPO define Tomahawk user configuration control procedures.

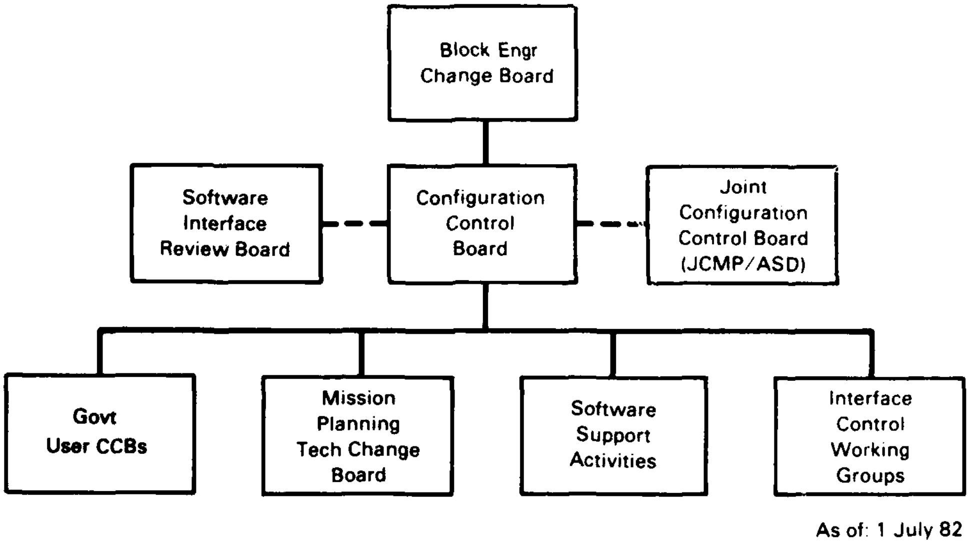

Fig. 7—Tomahawk configuration control organization

Block engineering change procedures have been established for production contracts and are monitored by the JCMPO Block Engineering Change Boards. Programmatic changes are analyzed for block incorporation, thus insuring proper development and testing. In addition, all routine Class I ECPs for production have pre-planned lot incorporation within established blocks. There were six outstanding Class I ECPs for the GLCM and SLCM beginning with the FY81 production contracts.

Any design change that occurs in a cruise missile variant is first submitted to the JCCB to determine its effect and to see if it should be made common across all variants. The JCMPO serves as the master configuration control agency to ensure that the variations between the missiles are in fact acceptable and do not interfere in any way with field operations. In order to be effective, configuration control must be applied to all missile system modifications.

Whenever possible, a change is propagated throughout the entire family of missiles so as to maintain maximum commonality. Consequently, design characteristics incorporated into one cruise missile may have a reverse commonality to another. This is in part because of the modular design of the GD/C Tomahawk cruise missile. The general rule is that the variant project that initiates the change must pay for all of the resulting engineering work even though it might eventually benefit some of the other variant projects as well. This is a form

of discipline to constrain the number of changes proposed. Although this has entailed considerable work on the part of the JCMPO to maintain, it is considered to be an essential part of the acquisition policy mandated by the OSD.

In the case of the ALCM, this function is defined in the Air Force Interface Control Plan (SSPO Document No. 208, December 15, 1980), which establishes a program for interface control among the major segments/equipments of an airborne weapon system. The purpose of the Interface Control Program is to develop and maintain a system of procedures and documentation that will ensure physical and functional compatibility between interfacing system segments/equipments. The program provides the means for interface identification, definition, documentation and control; resolution of interface incompatibilities; and for determination of the interface effect of all design changes. The basic plan sets forth the required elements (documentation and procedural) of the Interface Control Program.

The interface control activity for the ALCM is conducted under a working group chaired by Boeing. The Interface Control Working Group actually provides a formal structure for interactions between Boeing and the associate suppliers—namely the engine, guidance, and a few other components. The ALCM project office participates in, and monitors, those working group meetings but takes an active part only if necessary to resolve differences. If some working group action results in a configuration change across a subsystem interface, that configuration change is then coordinated with a JCCB that includes the JCMPO configuration control group. The latter action involves the JCMPO only if the configuration change involves something that interacts with the the GLCM, SLCM, or MRASM; otherwise the process is handled within the ALCM configuration control group.

Techniques Used for Reducing Test & Evaluation Program Cost and Time

In addition to providing opportunities for cost savings, the modular nature of the Tomahawk missile design and the extensive commonality present between SLCM variants and their derivatives allowed the JCMPO to save time and money in the SLCM T&E program, compared with a typical missile T&E program.[18] The JCMPO began working with the Commander, Operational Test and Evaluation Forces (COMOPTEVFOR) during 1977. One result was that combined SLCM DT/OT was permitted for the SLCM, which considerably shortened the test cycle, based upon an in-depth review of the SLCM T&E program by the JCMPO and COMOPTEVFOR. The proposed restructured SLCM T&E program that resulted from that review was approved by the Chief of Naval Operations on October 9, 1979, and permitted the revision of the SLCM T&E Master Plan to reflect the restructured program.

The restructured SLCM T&E program featured concurrent anti-ship and land-attack Tomahawk testing from both submarines and surface ships. This greatly reduced the effect of Tomahawk testing on fleet resources as well as reducing the number of flights and the duration of the anti-ship and land-attack submarine (launch) programs. The net result was that this approach freed up nuclear land-attack and anti-ship SLCM assets, providing the necessary missiles for conventional land-attack SLCM development testing without increasing the total number of production prototype missiles or of SLCM project test flights. Although the combination of service developmental and operational testing has become a common practice in the Air Force and was used for the GLCM program, this was the first time it had been done on a major Navy missile project.

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[18]A more extensive description of the T&E program is contained in Appendix C.

The modular design of the cruise missile permitted the use of a parachute Recovery Exercise Module (REM), which allowed the parachute section to be substituted for the warhead portion of the missile when not needed for that particular test. Through REM use: "Refurbishment cost of the recovered missiles is about 10 percent of the cost to purchase a new development vehicle. Besides this cost savings, the recovered hardware provides significant post-flight data [and] valid subsystem life expectancy information."[19]

As a result of the modular design, the missiles can not only be fitted with the REM system and recovered, but also configured for different missions by changing sections forward of the wings. Consequently, a missile originally used for a land-attack test flight can be converted for subsequent use in an anti-ship test. For example, one early Tomahawk missile was used for aerodynamic performance, TERCOM, Scene Matching Area Correlator, and TAAM test flights in seven successful air launches by having its configuration adapted for each particular mission.

Commonality of hardware and software between cruise missile variants also reduced the scope of the testing necessary in some cases. Because of the highly common airframe, engine, and guidance systems between the nuclear land-attack SLCM and GLCM variants, test data obtained for one variant was directly applicable to the other. Even in the anti-ship SLCM case, where a different guidance system is used (compared with the land-attack variants) data on airframe, engine, and warhead fuzing performance are applicable to other Tomahawk cruise missiles. For example, the GLCM program has been structured to obtain maximum benefits from the SLCM project. Compliance of the GLCM-configured missile with the common missile specification requirements will be verified by the SLCM project based on analyses, inspections, and tests. Data collected from GLCM and SLCM conducted tests will be used to support the analyses, and data requirements will be jointly established by these projects. In addition, ALCM data will be used to the maximum extent possible to support GLCM and SLCM tests.

MANAGEMENT AND CONTRACTING STRATEGY

The overall management strategy used in the cruise missiles project evolved over time as experience was accumulated and as the needs of the project changed. In part, of course, the strategy was influenced by the postures and actions of the industrial firms participating in the project, as well as by the internally generated goals and priorities. During the early part of the project, key elements of the overall acquisition strategy can be discerned to a large extent only through examination of the actions taken by the JCMPO. In only a few instances (notably the introduction of a second source for the F107 engine and the inertial navigation element) were records available that permitted tracing the consideration of options and that provided some insight into the specific reasons for a particular strategy decision. The minutes of the acquisition strategy board meetings, together with the resulting actions, provide a rich source of evidence regarding the evolution and application of acquisition strategy.

Although never specifically defined in project documentation, three broad objectives seem to have dominated the selection of acquisition procedures: (1) to achieve technical

[19]Hearings on Military Posture and House Resolution 5068, Department of Defense Authorization for Appropriations for Fiscal Year 1978, Committee on Armed Services, House of Representatives, February 22, 1977, p. 1097. Because of air vehicle learning curve effects, the present refurbishment cost is approximately 25 percent of that to purchase a new development vehicle.

maturity of the several different missile configurations and associated systems; (2) to provide a production base that would be reasonably secure from major disruption (strikes, natural disasters, etc.) and that could be quickly expanded to meet surges in demand; and (3) to control both current development costs and future production costs. Two main strategy elements were used to achieve those goals:

- Extensive use of commonality across missile models, combined with breakouts and competitive dual sources of supply during both development and production, and application of Design to Cost techniques;
- Flexible contracting, with the risk shifting from the government to the contractor as the project evolved and uncertainties were reduced.

Commonality across missile models was discussed above. Each of the remaining strategy elements will be briefly reviewed below, with additional detail contained in the appendixes.

Use of Breakouts and Competition

True competition is widely advocated by critics of weapon acquisition practice, but seldom practiced past the beginning of the full scale development phase except for expendable items with production runs of thousands or tens of thousands of units. In this project the quantities were large enough to make continuing competition at least a serious possibility throughout both the development and production phases, and the use of competition whenever possible has been one of the central themes of acquisition policy throughout the joint cruise missiles project. The extent of that competition for system development is summarized in Fig. 8 and for system production in Fig. 9.

In the four years before formation of the joint project office in 1977, competitions had already been held for selection of a Tomahawk airframe and for the engine and land-attack guidance system that would be used in both the Tomahawk and ALCM systems. In each of those competitions, a considerable amount of hardware demonstration was demanded as part of the source selection. One of the first major tasks of the joint office was to conduct a flyoff competition between Boeing and General Dynamics for the ALCM airframe; and by the time Boeing was selected as the winner, both missiles had effectively completed the equivalent of full scale development. A detailed description of the flyoff competition is contained in Appendix D.

Five other competitions have subsequently been initiated for *development* of various system components as shown in Fig. 9. But although competition during development is sometimes a cost effective approach and can yield a better product, at least the option for competition in *production* is required for the government to retain leverage on contractor costs, schedule, and product quality.[20] In order to be a viable option, however, either the government must acquire the design rights during development, or else an acceptable alternative system design must exist.

Several other considerations are necessary for successful implementation of competition. First, a comprehensive technology transfer plan (where appropriate) should be developed and

[20]Although production risk is typically considered an important consideration for second-sourcing complex systems, even a fairly simple subsystem may turn out to be difficult to produce. A good example is the MRA, where two different designs were carried into production, partly to reduce air vehicle vulnerability. Both designs initially proved difficult to produce, with early production rates far below expectations. Had the SLCM and GLCM systems been at rate production in parallel with initial ALCM production, it would have been necessary to install an older, less suitable radar altimeter in some missiles.

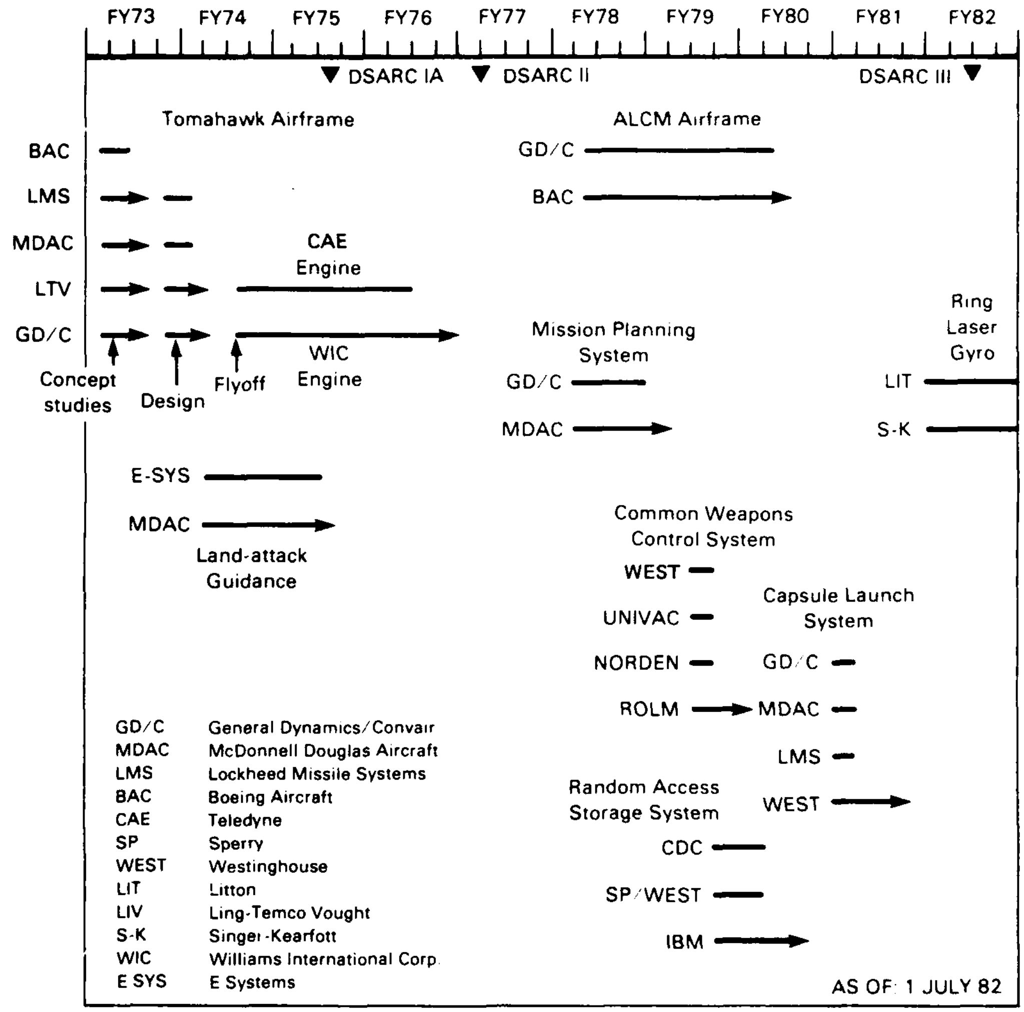

Fig. 8—Cruise missile development competitions

coupled with source selection to assist in reducing the lag time necessary to qualify the second source. This is not only of importance in the case of a critical project schedule, as in the ALCM case, but also minimizes project cost. Second, regardless of the competition form used, an effective award methodology must be developed in order to ensure a meaningful competition, particularly if a split buy is utilized during the production phase. Otherwise, the quality of the competition can be diluted, possibly leading to a higher Unit Flyaway Cost (UFC) than with a negotiated sole source contract. (For example, if a guaranteed minimum quantity is given to each contractor and the remainder is competed with no penalty clause present, a higher profit may result if a contractor charges an unreasonable price for the guaranteed quantity, even if it wins none of the competed portion.) Third, acquisition of rights in technical data must be pursued as early as is realistically possible during the development phase to provide the government with the broadest possible range of second sourcing options. In the F107 engine and land-attack guidance cases that was not done, which influenced the resulting second source implementation. Obtaining data rights of a given system

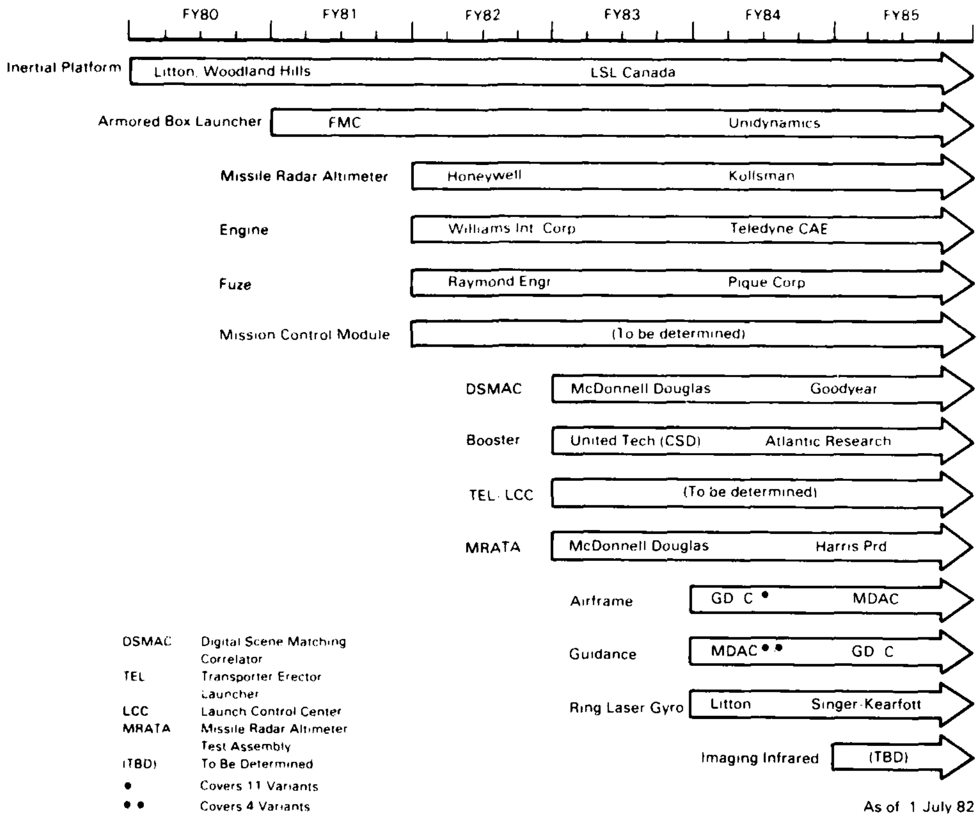

Fig. 9—Cruise missile annual production competitions

can provide the government with leverage over the contractor even if the system may not be second sourced. The resulting cost may, however, preclude this from being routinely performed. Obviously, issues pertaining to the financial effect of design changes on the acquired data rights must be considered by the government before its negotiation with the contractor. Finally, if the competition results in an identical design approach being utilized (as in Leader/Follower), both contractors must be assured equal terms of access to sources of subsystems, components, and materials; otherwise the cost may increase for both the guaranteed and split-buy portions of the contract. In addition, if an identical design approach is used, an effective procedure for configuration and quality must be instituted to avoid design divergence during the production phase.

Provisions for ALCM Production Competition. During the ALCM flyoff it was expected that a competitive dual source production phase might be desirable, and three options were incorporated into the competition RFP. The first was to proceed with a Leader/Follower dual source production, with the competition winner as the Leader and the competition loser as the Follower. The second was to use the winner of the competition as the Leader, but to competitively select the Follower. The third option was to not use the Leader/Follower ap-

proach, but to give the flyoff winner a sole source production contract with an option for multi-year procurement (MYP). By including these three options in the RFP to Boeing and GD/C, both contractors were required to bid on them, and because the government owned the data rights for both airframes, the contractors had to address these provisions seriously. The sole source option was later used after Boeing had been selected as the flyoff winner, in part because there were second sources for the engine and guidance system, and redundant suppliers for large portions of the airframe had already been developed.

As in most second sourcing cases, the cost benefits that result can be estimated only by comparing the otherwise sole source unit flyaway cost against the "front-end" cost that results from the competition, coupled with the resulting added administrative and O&S costs, and the UFC for each contractor. Because a quantitative cost variance discussion is not possible for the ALCM program case, only subjective impressions obtained from government personnel can be examined. The Air Force clearly received some benefits from the development competition, in terms of a better overall missile performance (improved range and decreased radar cross-section) and refinements in the production process (use of castings for body parts, etc.). For the production phase, however, the government decision was against second sourcing, choosing instead a sole source award with a firm fixed price incentive fee contract. The government later entered negotiations to use a MYP option for a FY83-FY85 buy to minimize ALCM cost growth. There was little Air Force interest in bringing on a second source, supposedly because such a process would be difficult to implement and might be too late in the program to result in any appreciable cost savings.

We can only speculate on any cost avoidance that might have been achieved if second sourcing had been initiated at the time of the DSARC III decision. Based upon a 1-1/2 and 2-1/2 year time to Follower qualification, Boeing would have produced approximately 1/6 to 1/3 of the total buy before the actual competition with the Follower. Given that the nuclear armed land-attack SLCM UFC decreased 9.2 percent in FY82 after completion of the AUR second sourcing agreement between contractors, the projected savings may have been between approximately $70 to $90 million (based on a similar 9.2 percent reduction in UFC).[21]

These estimated values may be overly optimistic for two reasons. First, redundant suppliers exist for the manufacture of the four main ALCM body tanks, reducing the number of components produced for the ALCM in a sole source mode. Second, the government might have had to purchase a technical data package (TDP) for the prospective follower. Although it was estimated at the time of the ALCM source selection that a TDP would cost approximately $40 million, the government was able to forgo the purchase at a TDP in the SLCM/GLCM AUR case for both the airframe and navigation/guidance system through the use of capital investment incentive clauses and because of the competitive environment. Even if a somewhat smaller reduction in UFC is used for projection, modest cost savings would probably have resulted regardless of whether the government was charged for the TDP.

If a Leader/Follower program were applied today, Boeing would have produced approximately 1/2 to 2/3 of the total buy before the actual competition with the Follower, based upon a 1-1/2 and 2-1/2 year time to Follower qualification, respectively. With the same two limit-

[21]This estimate is in terms of FY82 dollars and does not include the effects of converting the savings over the length of the buy to a present value. The discounted savings would be lower than the range given. However, the values shown here may be conservative because they are not based on a head-to-head competition between the two AUR contractors.

ing factors on performing a simple cost savings estimate applying here as in the previous case, this would project to savings of approximately $25 to $50 million for the ALCM (assuming a similar cost reduction percentage) if the second sourcing process was begun by the end of FY82. At this time, however, the government may well achieve greater cost savings by negotiating a MYP of ALCM Lots IV-VI (FY83-FY85) from Boeing than by attempting to initiate a Leader/Follower second sourcing competition.

Engine Production Competition. In the F107 engine case, a second source was desired to minimize production risk because the contractor (WIC) at that time was very small. (A more detailed discussion is provided in Appendix E.) Four different second sourcing methods were considered, including Leader/Follower and the development of an Alternate Cruise Engine (ACE). The principal issues relating to the different approaches were technical and production risk and cost. Considering the time and cost needed to develop a new engine, and because there was no reason to believe that the F107 engine had inherent design problems, the ACE option was probably used by the JCMPO largely to improve its bargaining position while negotiating with WIC on their degree of cooperative participation in various approaches to introducing a second source for the F107 engine. The approach finally adopted required WIC to select (with JCMPO approval) and qualify a second production source for the F107 engine.

Although production risk was the primary consideration that led to second sourcing the cruise missile sustainer engine, cost considerations as well as the proprietary data rights question affected the form of competition used. Even if an ACE could have been developed, the resulting delay in qualification of the second source would have required that factors other than cost be weighed (at least initially) in awarding any split-buy portions of the resulting competition because WIC would have had an advantage from learning curve effects. Furthermore, to consider developing the ACE for cost avoidance purposes alone would have required the engine to show a unit production cost somewhat less than that of the F107 to negate the considerably higher "front end" costs, estimated to be $67 to $110 million (FY78) more than the F107 Leader/Follower approach. When coupled with the fact that the ACE may have required a somewhat more sophisticated design than the state-of-the-art F107 to achieve the desired government performance increases, there is no clear evidence to suggest that pursuing this option would have been warranted solely on financial grounds.

The technology transfer process between the Leader (WIC) and Follower (TCAE) was not without problems. First, the cost to the government for the technology transfer process increased from the $18 to $19 million initially estimated by WIC to approximately $36 million (then-year dollars). Although this can be viewed as pure cost growth, the result did contribute to WIC's ability to produce the engine at the necessary rates, so some investment would have been necessary even with WIC in a sole source mode. In addition, JCMPO officials believed the technology transfer process improved WIC's production efficiency.

Second, although JCMPO performed extensive planning to aid in the technology transfer process between the two companies, a considerable delay occurred unknown to the JCMPO in the actual transfer of the data because the Leader released limited technical data to the Follower for a four-month period. Although this was corrected with no resulting schedule slippage, the government must clearly be capable of monitoring the technology transfer process to prevent these types of problems from occurring and the accompanying cost increases and schedule delays. (A more detailed discussion of second sourcing technology transfer process and government monitoring procedures is given in Appendix F.)

INE Subsystem Competition. In the INE case, the primary motivation for second sourcing was an attempt to reduce cost, with schedule and risk factors of somewhat less

concern than in the sustainer engine case. (A more detailed discussion is provided in Appendix G.) Two second sourcing options were considered for the INE: alternative design and technology, and Leader/Follower licensing. The perceived disadvantages of using the alternative design and technology approach included an increased life cycle cost (LCC) because of different designs, higher front-end development cost, schedule risk, difficulty in believing contractor cost and schedule estimates, and learning curve advantages for the initial source that again would have had to necessitate that non-cost factors be weighed in any competition for a split-buy portion of the contract.

The licensing approach initially considered would have resulted in the second source producing a design identical to that of the original developer. Because the government owned only limited data rights, however, the developer (LG&CS) could not be required to license items it claimed were of a proprietary design and developed with discretionary funding. As a consequence, LG&CS suggested a willingness to license a sister division (Litton Systems Limited (LSL)) of Canada to be the Follower. LSL had previously built several thousand of the critical components of the inertial platform for other projects, so the risk of this approach was estimated to be the lowest of any considered, and a lower LCC was expected. The resulting "front end" costs to the U.S. government were minimal for this dual sourcing case for three reasons. First, the Canadian government agreed to underwrite approximately $43 million in Tooling and Test Equipment (TATE) costs for LSL. Second, the JCMPO offered LG&CS a capital investment incentive clause to underwrite additional TATE that they required. Third, LSL was a sister division of LG&CS, so no royalty or licensing fee was imposed. The principal concern with this arrangement has been the issue of fair competition between the two Litton divisions. So far there is no evidence that fair competition has been restricted. However, the government must be capable of carefully monitoring the resulting cost proposals to ensure that fair competition, hence expected savings, do indeed occur in the future.

Tomahawk AUR Production Competition. Experience gained in devising dual competitive sources for the engine, INE, and other smaller components was applied to the latest, and by far the largest, dual source arrangement in the joint cruise missiles project—the Tomahawk missile. This plan actually comprises two separate but closely intertwined elements: the All Up Round (AUR) concept and the establishment of dual production sources for the AUR.

The Tomahawk family of missiles (SLCM, GLCM, and MRASM) was originally developed with GD/C as the airframe producer and flight vehicle integrator, and MDAC as the producer and integrator of the guidance subsystem. When the initial production of Tomahawk missiles became imminent, JCMPO began searching for a procedure that would shift a large degree of responsibility for production quality of the overall missile to the manufacturers, rather than just their individual subsystems. The ultimate objective was for industry to supply a complete flight vehicle, with a single point of responsibility for a missile reliability warranty (excluding engine and other GFE items). This concept was discussed at length, but no suitable contractual arrangement with both GD/C and MDAC was made because GD/C was unwilling to warrant the MDAC-produced guidance system. During that time the potential total production quantity of Tomahawk missiles began to grow, thus making more feasible the idea of establishing additional production facilities. The JCMPO then introduced the idea of establishing dual sources for missile production, with each source having full technical capability for both airframe and guidance. That offered the opportunity for simultaneously acquiring dual sources for the entire missile, thus achieving an expanded mobilization base, having the opportunity to negotiate future production contracts in a competitive envi-

ronment, and having each source be capable of warranting the entire missile. That warranted product came to be known as the All Up Round, consisting of a flightworthy missile contained in a launch compatible canister or capsule.

The key to such an arrangement was to successfully transfer both airframe and guidance technology to two firms so that each could have the technical knowledge to make design changes (a necessary condition if the firm is to warrant the product, because design changes may be needed to achieve the specified combination of reliability and performance). The most obvious solution was for GD/C and MDAC to exchange technology and each become an AUR producer, as each already had part of the necessary technology and each had the facilities and staff to assimilate the other's technology. In August 1981 the JCMPO initiated negotiations with GD/C and MDAC to achieve such an exchange. Both firms could see both potential gains and losses in such an arrangement; each could gain additional business, but at the expense of being placed in a more competitive environment. Negotiations extended over a period of several months and at times seemed to stall completely. However, neither firm held proprietary rights to important elements of their individual products, and JCMPO therefore had the theoretical capability to bring in a third party who would obtain manufacturing rights to both the airframe and guidance subsystems. That arrangement would obviously be to the disadvantage of both GD/C and MDAC, and when JCMPO established that as a possibility, both firms agreed to the necessary exchange between themselves.

On January 18, 1982, Mr. George Sawyer, Assistant Secretary of the Navy (Shipbuilding and Logistics), signed the Determination and Findings authorizing the JCMPO to enter into negotiated contracts with GD/C and MDAC for dual-source procurement of the AUR.[22] The resulting arrangement has several interesting features codified in a series of three MOAs (one between each pair of participants) signed in March 1982. One important feature is that the two contractors agree to reciprocally transfer all necessary technology, and that they are responsible for negotiating any licensing fees that they wish to accompany such an exchange. The government has agreed that those fees can be recovered as a contract cost, spread over the first 1200 missiles produced by each firm. However, the cost of such fees is expected to be quite small (between $20 and $25 million) in proportion to the total contract value, and competitive pressures between the contractors are expected to further reduce the amount actually charged to the government.

A second feature is that the MOAs contain certain incentives for the firms to carry out the technology transfer effectively and quickly. A detailed technology transfer plan was prepared during the first half of 1982, calling for a sequence of events spanning the following three years, with full qualification of each source to build the AUR expected to occur early in 1985. However, the technology transfer is expected to be sufficiently completed so that competitive bidding can occur for the FY84 and subsequent buys. The MOAs state that each firm will be guaranteed 30 percent of the missiles procured each year, with the remaining 40 percent to be allocated depending on bid prices. If the technology transfer proceeds on schedule, each firm will be guaranteed 40 percent of the total buy for FY84 and FY85. Failure to meet the transfer schedule will not only cause the firm(s) to loose the additional 10 percent guaranteed business but will also cause certain near-term penalties in reduction of progress payments for current production.

[22]A class 16 Determination and Findings was employed, whereby the service is empowered to negotiate contracts "when procurement by negotiation is necessary to divide current production requirements among two or more contractors to provide for an adequate industrial mobilization base." (Paragraph 32,681.10 of the Defense Acquisition Regulations.)

A third major feature of the arrangement is that each contractor has agreed to warrant the resulting AUR produced in his plant. The MOA between JCMPO and each contractor contains the following phrase:

> (contractor), as a production certified AUR supplier, shall be totally responsible for the delivery, support, and development of a warranty for the All-Up-Rouna missile system, defined as a flightworthy missile contained in launch compatible canister or capsule. The AUR delivery shall include demonstrated test compliance with Government approved acceptance test procedures.

The MOA also spells out exactly which parts of the overall system are to be GFE and which are excluded from the AUR. The details of the warranty are to be spelled out in subsequently negotiated individual contracts, but the government has achieved a posture where such a warranty is technically practical and where price and other features can be negotiated in a competitive environment.

The final feature of the AUR dual source arrangement is that it does not involve any direct investment by the government. Technology transfer costs are to be recovered over the first 1200 missiles, as noted above. Furthermore, TATE will be funded by the contractors themselves. A capital cost asset account was created by GD/C and MDAC with a total value of $175 million. Each contractor is allowed to write off the investment by factoring it into the overhead account, which is adjusted accordingly. That rate adjustment applies only to the AUR cruise missile contract to ensure the competition between contractors. Similarly, the term of the write-off was also negotiated with each contractor. One selected a period of 15 years, the other a period of 10 years. At this writing the actual changes in the overhead rate of the two contractors are unknown. The JCMPO expects that the writeoff will be somewhat "front loaded" so the actual magnitude will decrease over time.

The contractor's investment is protected through a capital investment incentive clause.[23] Here a production run of 1500 missiles is established as the baseline amount, after which the government has no cancellation liability for the TATE investment and the TATE becomes the property of the contractor. For every missile delivered up to 1500, the government's cancellation liability is reduced by 1/1500 of the total TATE investment by each firm. If, for example, production was terminated at 1400 missiles, the government would be liable for a cancellation charge of 100/1500 of the TATE cost and, upon payment of that charge, the TATE ownership would revert to the government. Under that circumstance, of course, it might be in the contractor's interest to release the government from the termination liability and thus retain ownership of the TATE.

A similar arrangement was used in the Litton INE production contract, but with some differences. There the method of writing off the investment to overhead was not specified, so the adjustment may have affected more than the associated cruise missile portion of overhead. Also, there was no cancellation penalty clause, so the contractor was at risk for the full amount of the investment if the project was canceled before the full expected production run had been completed.

One lesson learned from this experience is that the development program often does not yield tooling that is usable in the resulting production program. In addition, there has often been insufficient money allocated in the early production years for tooling necessary to build up to rate production levels. Numerically controlled tooling and the associated software are expensive and frequently not available early enough in the production phase because of

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[23] Section 3-815 of the Defense Acquisition Regulations authorizes the use of such clauses.

inadequate financial planning, funding shortfalls, or the lack of trained personnel. This has sometimes led to delayed implementation of the production equipment, which can lead to increased production cost and schedule delays. Allowing the contractor to amortize the tooling and test equipment cost "up front" over a guaranteed production quantity is a new and potentially effective way to solve this problem. This approach will be used by GD/C and MDAC for AUR airframe manufacture.

Where applicable, capital investment incentive clauses can be used to encourage industry to modernize its production capability without requiring "up front" investment by the government (unless programs are canceled). It appears to be an attractive contracting approach that can be flexibly applied in different situations and may well find more widespread application in the future.

In addition to the benefits accruing to the government from the expanded industrial base and the warranty provisions, it is expected that the AUR dual source arrangement will save money because of the price competition between the two suppliers. Such savings are notoriously hard to estimate, or even to determine in retrospect, but it is widely believed that savings of approximately 10 percent are typical when competition is introduced.[24] Future savings in the GLCM and SLCM projects may exceed $500 million (FY82 dollars) based on the airframe alone, as a result of introducing AUR dual sourcing. This estimate is based on an average UFC reduction of 7.9 percent achieved in the GD/C contract after negotiation of the MOA between GD/C and MDAC. Total project savings are expected to increase to between $1 and $2 billion if further UFC reductions are obtained for the airframe, as well as navigation and guidance, through head-to-head competition for all missile procurement beyond FY84, and if the MRASM reaches production.

Competition Summary. A summary of the characteristics of the many of the system/subsystem competitions performed by the JCMPO (and its predecessor, PMA-263) are given in Table 2. Systems/subsystems covered include: the Tomahawk airframe (AUR); ALCM airframe; sustainer engine (ALCM, GLCM, and SLCM); Improved Rocket Motor Assembly (booster) (GLCM, and SLCM); INE (land-attack) (ALCM, GLCM, and SLCM); navigation/guidance (AUR); ISA (MRASM); DSMAC (MRASM, and conventionally armed land-attack SLCM); MRA (all); Capsule Launch System (submarine-launched SLCM); ABL (ship-launched SLCM); and Theater Mission Planning (GLCM, and land-attack SLCM). A summary of cost savings where known for these systems/subsystems realized through competition and associated project management decisions is given in Table 3. In many cases the values given are projections, and it will someday be necessary to evaluate historical data to determine the accuracy of these estimates.

A brief summary of the CWCS competition (used for the GLCM and the ship-launched SLCM fire control) is given here, as it is too complex to include in the system/subsystem competition tables. Vitro is the integrating contractor and provides the basic system software, and MDAC provides the majority of the system hardware. For the Random Access Storage System (RASS), AN/UYK-19 data processing set, and Operator Interface Display Terminal (OIDT), separate subcontractor competitions were held by MDAC with JCMPO concurrence to select the sources. The RASS and AN/UYK-19 procured from MDAC are under consideration for breakout and direct purchase by the government from IBM and ROLM, respectively, for FY83. Plans are currently under way to procure the RASS through Leader/

[24]For a review of savings achieved in earlier competitive procurements, see K. A. Archibald et al., *Factors Affecting the Use of Competition in Weapon System Procurement*, The Rand Corporation, R-2706-DR&E, February 1981.

Table 2

SUMMARY OF CRUISE MISSILE SYSTEMS/SUBSYSTEMS COMPETITIONS

	Tomahawk Airframe (Prime)	ALCM Airframe (Prime)	Sustainer Engine ALCM, GLCM, and SLCM)	Current and Improved Rocket Motor Assembly (Booster) (GLCM, and SLCM)
How was competition initiated?	D: (a) P: (d)	D: (b) P: (a) (directed flyoff)	D: (a) P: (e) (F)	D: (c) (old design) D&P: (b) (new design)
If dual production exists, is it identical or alternate design?	Identical	n/a, sole source	Identical	Identical
Key competition objectives	(f), and improve reliability	(f), and best design	(f)	(f)
Development and production contractors, and dates selected.	D: GD/C (1975) P: GD/C, and MDAC (1982)	D: Boeing (1977) P: Boeing (1980)	D: WIC (ALCM, 1973; SLCM, 1975) P: WIC, and Teledyne CAE (1978)	D: ARC P: CSD(UT), and ARC (1981)
Mechanism of technology transfer	MOA and company funded technology transfer, L(GD/C)/F(MDAC)	n/a	L(WIC)/F(TCAE)	L/F (g)
At what point in the development and/or production cycle was competition introduced (and year)	D: Beginning (1974) P: Beginning (1982)	n/a	D: ALCM, Beginning (1972) D: SLCM, Beginning (1974) P: ALCM, GLCM, SLCM, Beginning (1978)	D: Early (1974) (old design D: Late (1981) (old and new designs) P: Middle (1985) (old and new designs)
Dual source production split	(h)	n/a	(i)	(f)
Contract types used in development and production	D: CPAF, CPIF P: FPI, FFP	D: CPFF P: FPI	D: CPAF, CPIF P: FPI, FPP	D: FFP P: FFP

Table 2—continued

	Inertial Navigation Element (ALCM, GLCM, and Land-Attack SLCM)	GLCM, MRASM, and SLCM Navigation/ Guidance (Prime)	Inertial Sensor Assembly (MRASM)	DSMAC (MRASM, Conventionally Armed Land-Attack SLCM)	Missile Radar Altimeter (All)
How was competition initiated?	D: (c) P: (b) (F)	D: (a) P: (d)	D: (b) P: (a)	P: (e)	D&P: (j)
If dual production exists, is it identical or alternate design?	Identical	Identical	Identical	Identical	Alternate
Key competition objectives	(f)	(f), and improve reliability	(f), and best design	(f)	(f), and increase vehicle survivability
Development and production contractors and dates selected.	D: LG&CS (1975)	D: MDAC (1975) P: MDAC, and GD/C (1982)	D&P: (k)	D: (l) P: (m)	D&P: Honeywell and Kolsman (D, 1978) (P, anticipated, 1982)
Mechanism of technology transfer	Technical assistance & licensing agreement L(LG&CS)/F(LSL)	MOA and company funded technology transfer, L(MDAC)/F(GD/C)	L/F (k)	L/F (n)	None, different designs
At what point in the development and/or production cycle was competition introduced (and year)	D: ALCM, Beginning (1972) D: SLCM, Beginning (1974) P: Beginning (1978)	D: Beginning (1974) P: Beginning (1978)	D: Beginning (1981) P: Beginning (1984)	D: Late (1982) P: Beginning (1983)	D: Beginning (1978) P: Beginning (1980)
Dual source production split	(o)	(h)	(h)	(h)	To be determined (not guaranteed)
Contract types used in development and production	D: CPAF P: FFP	D: CPAF, CPFF P: FPI, FFP	D: FFP P: FFP	D: CPAF, CPFF (MDAC) P: FPI, FFP	D: CPAF, CPFF (under MDAC) P: FPI, FFP

Table 2—continued

	Capsule Launch System (Submarine-Launched SLCM)	Armored Box Launcher (Ship-Launched SLCM)	Theater Mission Planning (GLCM, and Land-Attack SLCM)
How was competition initiated?	D&P: (b)	D: (b) P: (a)	D&P: (b)
If dual production exists, is it identical or alternate design?	n/a, sole source	(p)	n/a, sole source
Key competition objectives	(f), and obtain best design	(f)	(f), technical
Development and production contractors, and dates selected	D: Westinghouse, GD/C, and LMSC (1980) P: Westinghouse (1981)	D: GD/C (q) P: Unidynamics and FMC (1981)	D: MDAC (1975) P: MDAC (1978)
Mechanism of technology transfer	n/a	Existing drawings and performance specifications	n/a
At what point in the development and/or production cycle was competition introduced (and year)	D: Beginning (1981) P: n/a	D: 1976 (q) P: Beginning of production (1981)	D: Beginning of development (1978)
Dual source production split	n/a	(r)	n/a
Contract types used in development and production	D: CPAF P: Not yet determined	D: CPAF (GD/C) P: FPI, FFP, FFP with escalation	D: CPAF P: FPI (support contract)

Table 2—continued

Note:

D = Development phase	CPAF = Cost plus award fee	FPI = Fixed price incentive
P = Production phase	CPIF = Cost plus incentive fee	FFP = Firm fixed price
L = Leader	CPFF = Cost plus fixed fee	
F = Follower		

(a) Competitive negotiation by government with demonstration and testing.
(b) Competitive negotiation by government with no required demonstration.
(c) Elected by prime contractor before prime award, with demonstration.
(d) Directed class determination and findings (Exception 16), All-Up Round.
(e) Competitive negotiation by prime contractor with government oversight, no demonstration.
(f) Lower cost, decreased risk of interrupted or unsatisfactory production.
(g) CSD is the Leader and ARC the Follower for the Improved Rocket Motor Assembly (EX-111 MOD 0) (new design), ARC is the Leader and CSD the Follower for the current booster (MK-106 MOD 0) (old design).
(h) Guaranteed split for each contractor (30 percent), competed split (40 percent); may vary with incentives.
(i) WIC minimum and Teledyne CAE maximum guaranteed (sliding scale with monthly engine production rate).
(j) Competitive negotiation by prime contractor with government oversight, with demonstration.
(k) Contractor teaming used in development. LSL and Sperry are teamed with LG&CS and SK, respectively. Advanced selection of one of the two designs is planned for FY84, with a resulting production competition (identical design) scheduled for FY84 between the two contractors of the winning team.
(l) NAC, MDAC (1980); NAC design selected.
(m) MDAC selected as Leader (NAC design), GAC selected as Follower by MDAC (with JCMPO concurrence).
(n) MDAC: productionized with company funds; GAC: purchased from MDAC.
(o) Guaranteed minimum for LG&CS and LSL varies with monthly INE production.
(p) Alternate, based on GD/C original design.
(q) 1976 with GD/C and LTV air vehicle competition. Navy not authorized to proceed until FY78.
(r) Current plans are for a 100 percent competed first year buy, with selection of a single contractor for a second year buyout.

Table 3

CRUISE MISSILE COST SAVINGS REALIZED THROUGH COMPETITION AND ASSOCIATED PROGRAM MANAGEMENT DECISIONS PRODUCTION PHASE[a]

System/Subsystem	Past Savings	Future Savings (Anticipated)	Source of Savings
Tomahawk Airframe (Prime)	n/a	$536M (b) ($105K/unit ave.) (FY82)	Future: Unit cost avoidance.
ALCM (Airframe)	n/a	Unknown	Future: Potential multi-year procurement (FY83-FY86)
Sustainer Engine (ALCM, GLCM, and SLCM)	$28M	$240M	Past: Lower bid negotiated (somewhat offsets technology transfer cost ($36M)) Future: Unit cost avoidace.
Improved Rocket Motor Assembly (Booster) (GLCM, SLCM)	$10M	$50M	Past: Unit cost avoidance. Future: Unit cost avoidance.
Inertial Navigation Element (ALCM, GLCM, and Land-Attack SLCM)	$45M	$240M ($55K/unit) (FY82)	Past: Capitalized TATE and development costs. Future: Unit cost avoidance.
Navigation/Guidance (Prime)	n/a	Unknown	Future: Unit cost avoidance.
Inertial Sensor Assembly (Ring Laser Gyro) (MRASM)	$10M	$35M	Past: Capitalized TATE Future: Unit cost avoidance.
DSMAC (MRASM, Conventially Armed Land-Attack SLCM)	$5M	$15M	Past: Capitalized TATE Future: Unit cost avoidance.
Missile Radar Altimeter (All)	$5M	$24M (c)	Past: Capitalized TATE Future: Unit cost avoidance.
Capsule Launch System (Submarine-launched SLCM)	$2M	n/a	Past: Full scale development, lower bid negotiated.
Armored Box Launcher (Ship-launched SLCM)	$5M	$80M (d)	Past: Full scale development, lower bid negotiated. Future: Unit cost reduction.

a: M = million, K = thousands. Future unit cost savings for the Tomahawk airframe and INE are based on competition results to date.

b: Based on projected anti-ship, and nuclear and conventionally armed land-attack SLCM and GLCM costs after negotiation of MOAs with GD/C and MDAC. (Assumes GLCM airframe savings are same as for nuclear armed land-attack SLCM.) Total buy is assumed to be 4554, which includes GLCM (560), SLCM (3994), but not MRASM. Savings estimate may be conservative because it does not include savings from head-to-head competition between AUR contractors. Savings should also increase (up to $2 billion) if MRASM reaches production because of the large quantity currently planned (3500).

c: Actual savings may be less because of the initial producibility problems at rate.

d: Current plans are for a 100 percent competed first year buy, with selection of a single contractor for a second year buyout.

Follower second sourcing because the Army and Navy have adopted this system for other applications, increasing the projected quantities. In FY83, IBM (Leader) is expected to conduct a competitive selection (with JCMPO concurrence) for the Follower, who should also be qualified in FY83 and enter into competed split-buys with IBM in late FY84 or early FY85. Furthermore, it is expected that the OIDT furnished by Lockheed will be broken out for direct procurement by the government from Raytheon. (Although this information was accurate at the time of this report, the complex CWCS acquisition strategy may be modified.)

Three systems summarized in Table 2 warrant additional amplification because at least one aspect of the competition used was somewhat unusual. In the DSMAC case, a government laboratory (the Naval Avionics Center, NAC) competed its design against that of a contractor (MDAC) during the development phase. The NAC design was selected, so the government owned not only the data rights but the design and test data as well. This government design (with some MDAC features included) was then transferred to MDAC to produce. The NAC, with JCMPO coordination and funding, still serves as a focal point for RDT&E on the DSMAC system. Finally, the DSMAC subsystem was dual sourced for the production phase with MDAC designated as the Leader and GAC chosen by MDAC (with JCMPO concurrence) as the Follower. In the Improved Rocket Motor Assembly, the production competition RFP carried the stipulation that the contractor that won the award to develop the new booster (CSD) would become the Leader and bring the existing booster contractor (ARC) along as a dual source (Follower); in the meantime, the new contractor (CSD) would become a Follower to ARC (Leader) to set up a parallel production line for the existing booster. Consequently, there will be a period of time when both boosters are in production, thus assuring continuity of supply. In the ISA case, a competition was held to select dual developers. The selected contractors (LG&CS and SK) were then required to team with another contractor of their selection (with JCMPO concurrence). After qualification of the new team members (LSL with LG&CS, and Sperry with SK), which is estimated for early FY84, an advanced selection process is planned where the JCMPO will chose one design (also estimated for FY84). Following this, the winning team will be split, and yearly production competition between the two contractors for the identical design subsystem will commence.

The principal benefits seen by the JCMPO in the use of competition for the production phase have been to broaden the base of suppliers (strategic assurance of supply) while strengthening the industrial base down to the second and third layers, stimulate the development of new technical approaches, improve contractor responsiveness to government need, and encourage contractors to invest in new and better facilities.

Since the F107 engine technology transfer program, the government has not had to furnish any "front end" funding for JCMPO second sourcing because of strong contractor interest to become part of the cruise missile project and, in some cases, use of capital investment incentive clauses as described above. Although each DoD project has a different set of acquisition characteristics, it may also be possible to reduce "front end" funding in other moderate-to-large-scale projects using dual sourcing in production by providing similar incentives.

The extensive use of second sourcing did require that the JCMPO personnel become involved with the technical and production characteristics of the systems being developed, thus assuring tighter government oversight of contractor performance throughout the project. This imposes an added management burden, but without taking on this oversight function, the government has no real mechanism for identifying serious problems in the short run (as in the technology transfer case for the engine), which may lead to cost overruns and schedule delays in the long run.

A production planning and management organization needs to begin functioning shortly after DSARC II, to evaluate the contractors' manufacturing approach from engineering feasibility, cost, and schedule viewpoints as it evolves during the development phase. In the cruise missile program, as in most other DoD weapons systems programs, production personnel were first brought into the program about one year after DSARC II. Design problems tended to be identified and solutions proposed as the system became mature, but production problems continued well after that stage. In retrospect, a cadre of experienced production personnel probably should have been formed near the beginning of the development phase, permitting more reduction of producibility and schedule risks before the design was baselined and production begun.

In any Leader/Follower second sourcing arrangement, the Leader must be motivated to fully qualify the Follower as a competitor, otherwise cost growth may result. Incentives and disincentives should also be included in the resulting contracts if Leader/Follower second sourcing is used to ensure that the Follower is assisted, not penalized, during the period leading to qualification. In the JCMPO, award fees are typically used to motivate the Leader's management of the Follower. Issues surrounding the magnitude of the award to the Leader include: milestone accomplishments of the Follower, quality of the Follower's product, timely delivery of the Follower's product, and the Follower's cost. The government can use the Leader's performance during the period necessary to qualify the Follower as one criterion, in addition to cost, to determine the Leader's quantity from the resulting competitive split buy. Likewise, negative incentives, such as withholding progress payments and bad publicity resulting from a low award fee, may be used to ensure satisfactory Leader performance. The methods used, however, should be realistic to ensure that they have an effect.

Technology Transfer

Experience in the cruise missile program strongly suggests that the government must take an active and continuing role in the Leader/Follower technology transfer process. For example, when an identical design, Leader/Follower form of second sourcing is used, the program office must ensure that the Leader does not impose more stringent standards upon the Follower than he himself would have to follow. That can easily result in a more costly product being made by the Follower. To prevent that from occurring, and to ensure fairness between the two contractors, the government or other neutral party must be prepared to monitor the technology transfer process closely by going to each plant and seeing that the same standards are being applied to each contractor. One approach the JCMPO used was to select a small number of parts or components and examine the production processes used by each contractor in detail for large differences.

A related issue in the administration of identical design, Leader/Follower second sourcing programs is that the government must ensure, through contractual incentives if required, that the technology transfer program is proceeding on schedule between the contractors. In the F107 engine second sourcing program, the technology transfer process appeared to be going smoothly, but JCMPO Production Division personnel discovered that F107 technical data were not being made fully available to the Follower. Several factors inhibited the government surveillance process from working adequately:[25] A coordination problem existed between Defense Contract Administration Services offices because WIC and TCAE are

[25] Rosemary E. Nelson, "Leader/Follower Second Sourcing Strategy as Implemented by the Joint Cruise Missiles Project Office," Masters Thesis, Naval Postgraduate School, Monterey, California, September 1980, pp. 67-68.

located in different administrative regions; WIC and TCAE were not required to report the status of the technology transfer process at program reviews (although that problem was eventually identified at the first production readiness review held at TCAE, some form of program review was needed earlier in the technology transfer process); only a small number of JCMPO personnel were available to monitor the program; and the incentives and disincentives between the JCMPO and the contractors were inadequate to ensure the success of the technology transfer process. Incentives and disincentives have since been used in more recent second sourcing competitions (i.e., the AUR), together with closer government supervision to prevent problems of this type in the future.

Obviously, in a system as complex as the F107 engine, hidden knowledge (or intellectual property) may be critical if the Follower is ever to become qualified. Before the initiation of the technology transfer process, the government must ensure that the data to be passed from the Leader to the Follower include sufficient information for total system or subsystem production. Consequently, in some cases it may be beneficial to the government to establish firm milestones for the Leader to provide the necessary information, and for the Follower to absorb it.[26]

For simpler subsystems (i.e., an airframe), the government must also ensure that uncoordinated design approaches are not pursued after the technology transfer process has been completed and the Follower is a qualified producer. In the JCMPO, a JCCB was established to ensure that commonality was maintained both within a given subsystem design and between cruise missile variant programs.

In addition, if minimum guaranteed percentages or quantities are specified in a split buy competition, a provision should be included in the MOAs or MOUs and in the contracts for technology transfer between the contractors and government to ensure that the contractors charge a "fair and reasonable cost" for the items to be delivered. There is always the possibility that one contractor may realize that it can not compete with the other and hence will not win any competitive portion of the split buy. Although this possibility has not occurred in the cruise missile program, at some point it might be in a contractor's best interest not to compete but to claim exorbitant costs for the items produced under the guaranteed portion of the split buy. The government should utilize the MOAs or MOUs, as well as the contracts, to provide it with an option for potentially disqualifying a contractor that would use such a strategy. This protection was implemented in the guidance (INE) and AUR technology transfer processes.

Design to Cost

Design to cost (DTC), as used in the early conceptual and project development phases of the cruise missile project, was focused on performance versus cost tradeoffs. Before the DoD accepted DTC, performance objectives had often been defined as absolutes, unbending and unquestioned. This approach was replaced by the Navy cruise missile office and by the JCMPO with one of achieving an acceptable level of performance within a defined range. The lower limit or threshold establishes the minimum acceptable level, and an upper bound or goal defines a desirable level, if it is affordable. With cost as a design parameter equal to the performance criteria, a new variable is added. Based upon mission objectives, a maximum

[26]George F. Sparks, "Direct Licensing in Major Weapon System Acquisition," Masters Thesis, Naval Postgraduate School, Monterey, California, September 1980, pp. 76-77.

affordable cost, which is a threshold, is established. Because cost reduction is desirable, it is encouraged by defining a cost goal at some lower but achievable level. Consequently, an optimization is performed between boundaries defined by cost and performance thresholds and goals.

The DTC starting point on the Tomahawk involved the use of evaluation criteria, which in order of importance were: range; operability (including compatibility, reliability, and handling); survivability; UFC; prelaunch shock resistance (for sea launched applications); potential for adaptability to air launch from a B-52; design for modification of the land-attack cruise missile to anti-ship cruise missile (including economic advantage of commonality, maneuverability, and range); adaptability of land-attack and anti-ship cruise missiles to surface ship launch (from a submarine launch platform); and adaptability of land-attack and anti-ship sea launched cruise missiles to land launch (GLCM). Specific values of thresholds and goals were quoted for each of these criteria.

An example of this process is given for range optimization. An airframe configuration was first synthesized and its cost and performance estimated. Then an analysis postulated ways to increase performance and decrease cost. This led to the definition of alternative configurations and approaches, which was followed by the determination of cost and performance for each alternative. This procedure was iterated until an optimum baseline configuration was determined. Following this, a re-evaluation of the criteria was performed in the order of precedence to ensure overall system acceptability.

GD/C performed three levels of tradeoffs leading up to full scale development (FSD), including system level, configuration level, and detail level trades (10, 30, and 300 studies, respectively). An example of a system level tradeoff was the launch concept selection. Here, encapsulation was chosen over a bare missile, and separation in the launch tube was chosen over separation in water or air. Such studies were then used in the definition of missile configuration. Examples of the configuration level tradeoffs performed include the inlet duct (deployed scoop chosen over a flush and hybrid scoop); fin arrangement (cruciform over curved); and the wing arrangement (two-piece mid wing over a one piece top wing), which led to a wing configuration tradeoff (conventional design chosen over a supercritical design). Such tradeoffs were then used in the definition of the detailed design studies. Examples include the shroud material (aluminum over steel), fin actuator (electro-mechanical over hydraulic), and body construction (machine and weld over riveted).

During the FSD phase, DTC activities emphasized producibility (including selection of specific materials), manufacturing methods/processes, application of Military Specifications, electromagnetic pulse shielding, and similar factors. Additional tradeoff study topics included comparison of a common missile design versus a family of missiles (AGM-109, GLCM, and SLCM), each specialized to a particular mission and launch platform; and alternative concepts for Integrated Logistics Support. An example of mission/launch platform tradeoff studies was one that resulted in a recommendation for the air, ground, and ship and submarine launch platforms to consider the use of no capsule or booster, an aluminum canister, and a steel capsule, respectively. A summary presentation of some of the more important DTC design and producibility tradeoffs performed by GD/C is given in Fig. 10.

The major features of the GD/C DTC plan included: cost being equal in importance to performance, the use of a rigorous and continuing trade study activity, the use of subcontractor DTC plans, the definition of LCC contribution, the use of a step-by-step procedure, the definition of responsibilities and reporting requirements, and the use of discrete performance periods for evaluation purposes. The DTC process established and defined target costs, made

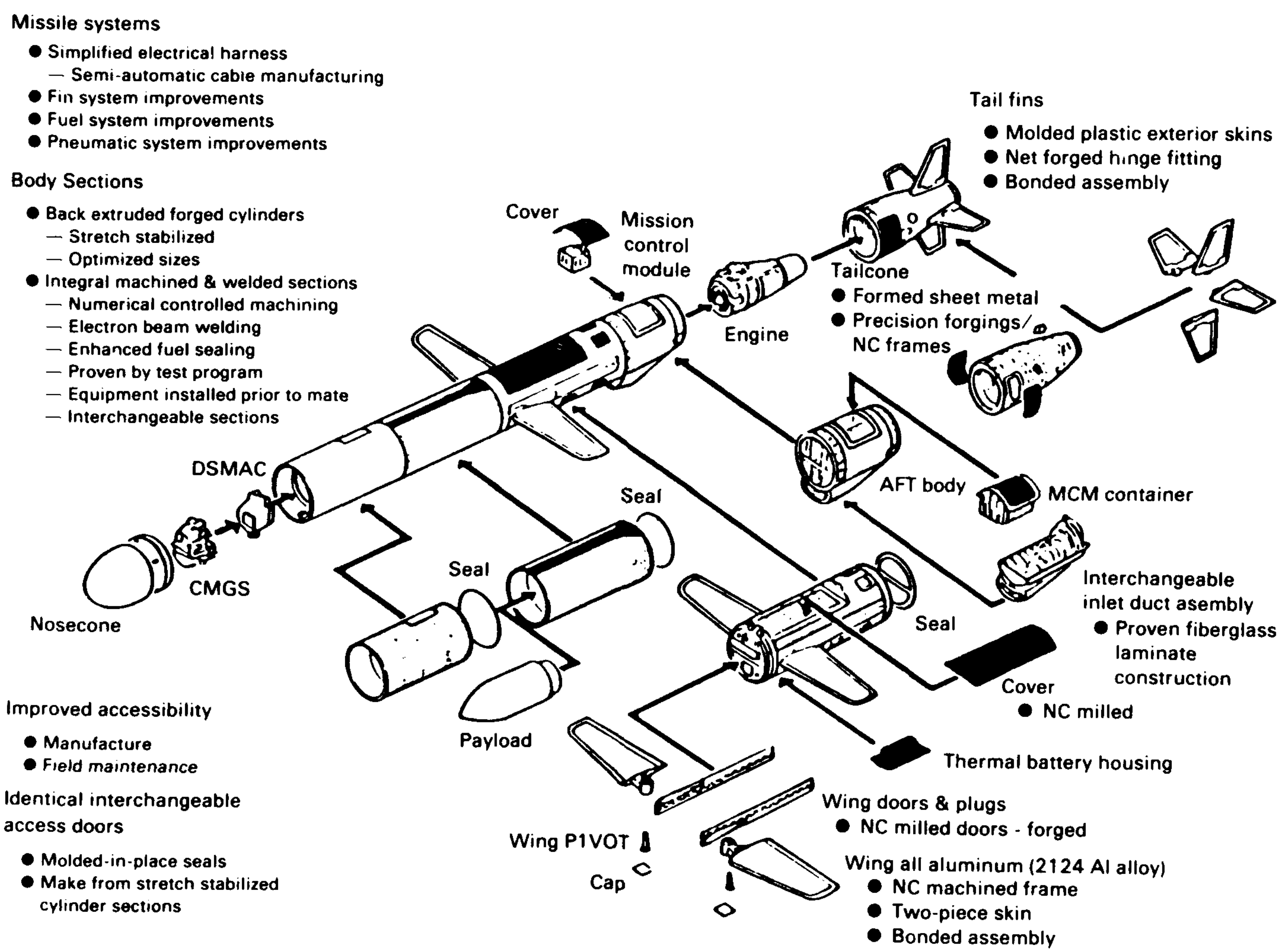

Fig. 10—Tomahawk DTC design and producibility enhancements

current costs available to all decisionmakers, used these targets as principal design parameters, tracked and fed back updated predicted costs, used manage-to-cost by setting further year costs and used manufacture-to-cost by collecting actual costs and monitoring trends. One use of this was the determination of target versus predicted costs and the resulting variance that would be expected. The DTC documentation provided the JCMPO and GD/C management with real-time visibility into the design evolution process and projected costs, documented trade study results, emphasized cost traceability, included unapproved data that was more timely than "official" data, and included potential changes. This documentation was submitted at the end of each discrete performance period and included a design description for each item as well as manufacturing and procurement plans.

At the subcontractor level, the DTC activity was used as an integral part of the overall DTC plan. The design criteria for each subcontractor design task included a unit production cost criterion that was given equal priority with all other criteria. The DTC process was coordinated and integrated through the use of subcontractor design reviews, with GD/C retaining the final decision authority for all subcontractor system level trade studies to be performed.

The will-cost demonstration and philosophy has been used as a budgeting, negotiating, and source selection tool by the JCMPO. It involves techniques of "should cost" for a given system and is used for cost projection and in evaluating prototype hardware that is similar to production hardware for determining producibility. The cost of prototype hardware is estimated from actual experience and comparison with the development plan and through substantiation of actual expenditures. The similarity of the prototype hardware to production hardware in terms of possible cost growth is based upon a detailed description of the system, with emphasis on the required changes; the cost of these changes; and a substantiation of costs. These data are then used in a cost model that predicts current estimates for production cost, as well as detailed backup for these estimates (experience curves).

Contracting Approach

The several different models of cruise missiles were being developed simultaneously with their key subsystems, with the inevitable risks and uncertainties that are normally associated with such a fast-paced project. During the development stage it was common practice to use cost-plus-award-fee contracts—the costs were directly paid by the government, and an award fee was added to provide incentive. A base fee of 3 percent was typical, with an additional award ranging from 0 to 12 percent, based on contractor performance. In practice the highest award fee was about 8 percent, but the average was closer to 3 percent, yielding a total fee of 6 percent of costs. The award was based on a clearly specified set of criteria, but the final determination was basically a subjective decision by the senior JCMPO managers. In some cases, later in the project when smaller subsystems were being developed and the system configuration was more mature and well defined, a cost-plus-fixed-fee or cost-plus-incentive-fee contract was used.

As each individual system element moved from development to initial production, the contract form changed, typically to some form of fixed price. Usually the first two or three years of production would be through fixed price incentive contracts, with the contractor absorbing 25 to 35 percent of any overruns up to a specified ceiling price. After two or three years of production the project usually became quite stable and prices predictable, and thereafter a firm fixed price contract was used.

The form of contract used in each of the major JCMPO development and procurement actions is included in Table 2.

Multi-Year Procurement. Legislation has recently been passed to make multi-year procurement more practical. The use of such contracts requires that the configuration be stable and that production quantities be reasonably predictable (although quantity options can be used to provide some flexibility). The production phase of the ALCM and SLCM are now approaching the point where the necessary conditions exist, and the Air Force is negotiating a multi-year contract for ALCM production starting in FY83. The JCMPO, however, believed that it was in the government's best interests not to pursue MYP at this time in the Tomahawk project because of factors that would negate any potential benefits.

A principal concern was related to the state of flux that the GLCM, SLCM, and MRASM projects were in then, as well as today. One U.S. position in the Intermediate Nuclear Force Talks might involve the cancellation of the GLCM and Pershing II deployment if the Soviets eliminate their SS-20s and other missiles. Consequently, the fate of the GLCM program in terms of production is uncertain at this time. Similarly, the SLCM procurement quantity has changed substantially over time.[27] Until October 1981, there was not approved program IOC data for deployment of the nuclear-armed SLCM. In addition, considerable differences existed during early 1981 between the number of SLCMs recommended for procurement between the President's Budget and Navy planning. Finally, with the Navy's attempted withdrawal frcm the MRASM program and difficulties in developing the munition for the Air Force variant, the production stability of this program is questionable. Once these factors have been resolved, then MYP might become a more desirable alternative. Until then, however, the firm quantities to be procured cannot be identified.

A second factor that influences the use of MYP by the JCMPO for these systems involves the current dual sourcing and associated MOAs. The MOAs, which were reviewed and approved by the Naval Material Command, stipulate that the government shall not enter into other agreements for any other source and/or second source for either system that uses the same generation or general type of technology as existed in 1978, the date the MOAs were signed, except as provided in the MOAs. In developing the approach to ensure competition in the production phase, the JCMPO outlined plans for encouraging competition throughout the life cycle of the project. Splitting the yearly quantities into separate multi-year buys between the contractors for any of the competed subsystems would not alleviate the problem of unknown out-year quantities. If competition is to be be effective, these procurements would have to include fully priced options for firm requirements. As previously discussed, this is highly unlikely at the present time for all but the ALCM airframe and the ABL, where plans are being formulated to use MYP for each of these systems.

QUALITY ASSURANCE IN MANUFACTURING

The ALCM and Tomahawk derived cruise missiles will spend a large portion of their life in storage. Unlike airplanes, they are not exercised regularly to identify component failure modes, and only a few will be randomly selected for testing purposes. Therefore, quality assurance in production is important to the success of the cruise missile.

Early in the joint cruise missile project it was decided to use reliability warranties as a management procedure to ensure that the contractors would place system reliability at an appropriate level of importance during both the development and the procurement phases. By

[27]This is discussed in greater detail in Sec. IV and Appendix I.

establishing a specific level of reliability as a goal and negotiating a price, the producer will charge for assuming full responsibility for meeting that goal, and system reliability can be brought to a high level of management visibility for both the producer and the project office. Cruise missile reliability warranties were first investigated during the early phases of the SLCM project but were not implemented then because the project had not progressed to the production phase. The ALCM program was the first cruise missile version to reach production and thus was the first opportunity to negotiate specific warranty clauses.[28] At the time of this writing, three warranty contracts have been negotiated for different elements of the ALCM: the F107 engine, the INE, and the airframe. Details of those are described in Appendix H.

Reliability and availability warranties are fairly new instruments in weapon system acquisition management, and their implementation and effectiveness are not well understood. Considerable effort was required to negotiate the three ALCM warranties described above and to gain their approval from the Air Force and Navy hierarchies. Additional warranties (covering the SLCM/GLCM airframe and guidance elements) are now being negotiated.

All of these warranties are early in their coverage period, and empirical evidence is limited. Design changes have been made to both the engine and the INE under the warranty clauses, and manufacturing quality of the warranted components appears satisfactory, as is the actual performance of the warranted systems. In 1978, before military qualification, at least some quality assurance problems existed at WIC (sustainer engine) and MDAC (guidance system), but steady progress has been made since then by both contractors to alleviate those problems.[29] Both Boeing (ALCM airframe) and Litton (INE) have demonstrated a high level of quality control throughout the cruise missile program. However, it is not possible to identify the extent to which warranties have contributed to these results.

Although the cost of the warranties has been the subject of hard negotiation, their value will be measured in terms of how effective they are in persuading the contractors to develop and produce missiles that achieve and maintain a high level of operational readiness and that perform properly when launched. If the warranties are successful in that regard, their total cost to the government of a few million dollars will be minuscule when compared with the value received by the operational user.[30] Unfortunately, an evaluation of cost vs. benefit may yield ambiguous results even after several years of experience. If the missiles do meet the reliability and availability goals, it can only be presumed that the incentive fees and warranty allowances provided in these instances did in fact make some contributions to that end. If the goals are not achieved, we will be unsure if the warranties were underpriced or if the technical challenges were simply underestimated by all concerned. In any event, it may be several years before enough field experience has been accumulated to determine if the reliability and availability goals have been achieved.

As noted in the discussion on contracting, the JCMPO tried unsuccessfully for several years to consummate a warranty to cover the Tomahawk air vehicle. The lack of such a

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[28]These warranties were negotiated near the end of the flyoff competition managed by the JCMPO.

[29]Some preliminary indications of reliability and product assurance can be seen in WIC's performance in building the F107 engine. There have only been two engine-related flight failures in the GLCM, SLCM, and AGM-109 programs to date. Both of these occurred early in the SLCM program, before F107 engine qualification. As of our mid-1982 cutoff date, there have been no engine-related failures in the last 64 consecutive Tomahawk test flights. This string of test successes is a considerable accomplishment, particularly in light of the early uncertainty as to whether WIC could achieve the necessary production rates.

[30]Even though investment costs of warranties are typically small, they have not gained widespread acceptance in DoD programs because of the "up-front" funding that is required.

warranty has been accompanied by the most serious quality assurance problems experienced in the cruise missile program to date.

Tomahawk Airframe Quality Assurance Problems and Government Reviews

Quality assurance problems have existed on and off since mid-1978 in the Tomahawk airframe at GD/C. The source of this quality assurance problem appears to be one of manufacturing and engineering discipline, and not the air vehicle complexity. (A rough estimate of the number of operations required to produce the Tomahawk airframe is 7000, and almost 450,000 are needed to produce the B-1 airframe.) In an effort to increase quality assurance, personnel with production backgrounds were brought in from other divisions of GD, and pictorial planning was implemented in an attempt to minimize manufacturing discipline problems.

Early in the development phase, there was little evidence of quality control problems at GD/C. The Tomahawk (SLCM) successfully passed the DSARC II, the GLCM was initiated, and GD/C entered into a competitive flyoff with Boeing for the ALCM. However, in mid-1978, flight tests began to reveal problems. On July 25, 1978, two anti-ship SLCMs were launched from a submarine and both failed to achieve sustained flight because of shroud and booster separation failures. This double failure caused the JCMPO to examine GD/C quality assurance procedures. The next SLCM launched (September 14, 1978) also failed because of shroud assembly problems. The director of the JCMPO suspended further flight testing at that time.

Two reviews, one led by Mr. Schubert for the JCMPO and one led by Rear Admiral Barrineau for the CNM, examined the source of these failures and made recommendations to improve GD/C product assurance. Although the source of these flight failures was an assembly or manufacturing discipline problem, the pyrotechnic subsystem design was a contributing factor.[31]

One conclusion of the reviews was that there was insufficient documentation to support production of the missile. Although the flight failures were due to air vehicle design problems, a weak set of manufacturing instructions were believed to have been contributory.

Following design changes and subsequent testing, the Tomahawk cruise missile compiled an impressive record of flight test successes from October 1978 through the beginning of November 1979. Of the 19 flights during this period, 16 were judged successes, and only one of the three failures was caused by an airframe-related problem.[32]

Beginning in mid November 1979, however, there were three successive AGM-109 flight failures. One of these was clearly due to air vehicle problems (no wing deployment), and a second was due either to a guidance system or to an air data sensing system (airframe) problem. The JCMPO directed the flight decertification of the AGM-109 and an investigation

[31]An example of inadequate manufacturing discipline was an unauthorized repair to one vehicle (T55), which was not in the quality assurance record and would have resulted in a flight failure had it remained undetected. This form of problem is serious because individuals without the proper background making such changes may do so without knowing the consequences that may result from their actions. Although additional funding may help solve engineering discipline problems, it will not in itself solve problems due to manufacturing discipline.

[32]After examining available records for Tomahawk flights through our mid-1982 cutoff date, it was difficult in some cases to determine whether a given failure was related to airframe problems. Complicating this was that valuable test data were sometimes obtained on flights of short duration where the missile unexpectedly crashed. In addition, in some cases where the crashed missile was unrecoverable, or even if recovered it could not be properly tested, only an estimate could be made as to the source of the failure. We recognize these limitations in this discussion of product assurance.

of the Tomahawk (including AGM-109) headed by Lt. Col. Wolff. After that review was completed in January 1980, the remaining two AGM-109 flights were successes.

Two of the next four GD/C SLCM flights from August to mid December 1980, however, were failures related to airframe problems.[33] Pursuant to a request from the Vice Chief of Naval Operations, the CNM directed the formation of a team to review the recent Tomahawk test failures. That review, headed by Rear Admiral Catola, began at the end of December 1980 and concluded in February 1981. Engineering design deficiencies noted in the Catola review included problems associated with the (submarine launch) capsule front seal and venting of the REM.

The Catola review stated, in the Executive Summary of its Report,

> Although great strides have been made at GD/C in descriptive planning and in updating facilities in the final assembly area, all of the contractors visited, including GD/C, have problems in discipline, control, and procedures. For instance, there were inadequate work instructions at MDAC and Rosemount (the GD/C air data subsystem supplier); intermixing of non-conforming and conforming material at GD/C, MDAC and Rosemount; poor procurement quality assurance at GD/C; deficient internal and external auditing at GD/C and Rosemount; and inadequate work instructions for production refurbishment at MDAC and GD/C.[34]

Six of the next seven Tomahawk flights between mid January and July 1981 were successful, with the remaining flight a partial success. On July 30 and on August 2, 1981, two successive Tomahawk flights failed. The second failure was due to a problem in the airframe's power switching amplifier.[35] However, the source of the first failure was unclear. It was believed to be related to either the DSMAC hardware itself or a shock induced to this hardware when the cover over the subsystem was removed by a pyrotechnic charge shortly before use.[36]

Rear Admiral Locke started an investigation after those two flight failures and directed the decertification of the anti-ship SLCM in September 1981. In November 1981, the anti-ship SLCM T-46 was disassembled by a team of JCMPO, contractor, and NAVMAT-06 personnel in order to evaluate product quality. The disassembly revealed a number of design and workmanship problems that were assessed as high or moderate risk for design and manufacturing. The T-46 disassembly team confirmed that the symptoms and problems previously discovered still existed, actions performed to that date had been ineffective, and specific corrective actions and special management control were required. Major areas of concern that

[33]Missile T27:2, launched on December 16, 1980, was listed by GD/C as a success. Although the primary objective was met, a design problem associated with the parachute door caused it to impact prematurely 41 seconds after launch. The same problem, parachute door failure during a submarine launch, also occurred in T24:4 on August 7, 1981, which was listed by GD/C as a failure. In addition, both flights had the same stated objectives—maximum depth, maximum speed launch. The primary difference between these flights was that the problem associated with the parachute door in T24:4 affected the *underwater boost phase,* while in T27:2 it affected the missile flight *after it had broached the surface*. Both flights impacted shortly after launch because of this problem.

[34]The Catola review was somewhat critical of the JCMPO Configuration Management, T&E, and Systems Integrator roles, in large part because of insufficient staffing. The JCMPO had difficulty at that time in obtaining both billets (in part because of a Federal hiring freeze) and qualified personnel. An additional discussion of this is given in Appendix A.

[35]Flight failures that occurred on August 2 (T41), November 7 (T54), 1981, and March 30, 1982 (T56) were traced to a design deficiency in the airframe's power switching amplifier. Although the source of this design problem was related to failure to use standard industry practices in constraining the printed circuit boards, neither GD/C nor any of the numerous government inspection teams recognized this potentially faulty design before the third flight failure that resulted from it.

[36]While the source of this problem was being investigated, another conventionally armed land-attack SLCM (T55) was removed from the assembly line and disassembled. A severe assembly quality control problem was discovered—an inert pyrotechnic device was found installed in the missile. In addition, although the ejection end of the device was wired, the firing end was not hooked up. Consequently, even if a live pyrotechnic device had been installed, it would not have fired. JCMPO personnel indicated that this would have resulted in a flight failure. This missile was refurbished and later performed a successful mission on May 21, 1982.

resulted from the disassembly included: design producibility that contributed to quality problems, inadequate developmental specification application carried into production, data submittals that were inadequate and poorly utilized, inadequate subvendor control, and a lack of discipline at all levels. (A later disassembly of an additional missile (T-49) revalidated the findings of the previous T-46 disassembly.) Several actions were taken that addressed the problems revealed by the T-46 disassembly, including: the installation of production-grade hardware, design modification of one component and rework and replacement of another, on-site inspections at contractors and subcontractors by JCMPO and NAVMAT-06 personnel for critical components, GD Corporate and Convair Division commitment to improve their quality assurance program, and the use of a quality assurance tiger team to assist contractors and vendors.

After the flight failure of a conventionally armed land-attack SLCM (T53) on December 14, 1981, on-site reviews were initiated at all Tomahawk contractor facilities. Beginning on February 25, 1982, with the first Tomahawk flight after initiation of the contractor reviews, six of the next nine flights through our mid-1982 study cutoff date were successes, and one of the other three flights was a partial success. Although the partial success was due to an anti-ship seeker problem, the other two failures were due to airframe problems.[37]

DCASPRO Method C and D Actions

The review conducted by Rear Admiral Catola identified 39 product assurance problems or concerns, 14 of which remained open as of July 1, 1982. Five Defense Contract Administration Services Plant Representative Office (DCASPRO) Method "C" corrective action requests were issued in response to what the government perceived to be a serious quality assurance problem at GD/C. The Method "C"s issued included ones for planning and work instructions (November 6, 1981); ineffective GD/C corrective action audit findings (November 18, 1981); control of non-conforming material (January 19, 1982); drawings, documentation, and changes (February 3, 1982); and material control (May 27, 1982). A Method "C" corrective action request is unusual in the Aerospace industry, and for a major aerospace contractor to receive five of them on one program in such a short period of time, and for these actions to remain open, may be unprecedented in recent years.

These open Method "C" corrective action requests, letters from DCASPRO and the JCMPO pertaining to the unsatisfactory condition at that time of Convair's Quality Control System, and the absence of satisfactory corrective actions led to the issuance of a DCASPRO Method "D" corrective action for the Tomahawk cruise missile program on June 22, 1982. The Method "D", as authorized by NAVMATINST 4355.69A, is a very serious step for the contracting officer to take, and is never invoked precipitously. Basically, a Method "D" action is an expression of "no confidence" in a contractor's quality control system, as required by MIL-Q-9858A, and is taken only "after sequentially exhausting every other avenue available by the Government to obtain corrective action by the manufacturer." A result of this action was for DCASPRO to "terminate our 'DoD Stamp' endorsement of a contractor's quality

[37]Several failures during the course of the Tomahawk flight test program were the result of problems with the anti-ship seeker. Although security restrictions prohibit our discussing this matter in depth, part of this problem was related to hardware and software implementation differences between the Tomahawk and Harpoon, as well as the operational test environment. In any event, these failures *were not* the result of airframe hardware reliability or quality assurance.

control."[38] Although the traditional Method "D" action "contemplates a complete cessation of Government inspection and acceptance and a termination of hardware deliveries," the DX priority of the cruise missile program resulted in a temporary modification of this procedure, which in reality was to provide GD Corporate and Convair Division with an opportunity to resolve these problems without halting cruise missile production activities at GD/C. As stated in a follow-up letter from DCASPRO to GD/C on June 24, 1982, if "during the next 120 days the Government's confidence in the GD/C Quality Assurance System applied to the cruise missile program is not measurably improved, further action will be taken by the Contracting Officer within the alternatives available under the applicable contracts."

At the time of this writing, the 120-day period had not concluded so the results of this action cannot be reported. However, the JCMPO expects that the competitive environment that will be created through the continued implementation of the AUR dual source procurement, together with the associated warranty clauses to be negotiated, should further encourage the correction of any lingering quality control problems.

In retrospect, it is interesting to examine whether a higher level of Tomahawk airframe product assurance could have been maintained. These product assurance problems were clearly not an inevitable consequence of exceptionally high design complexity. To date, Boeing has not had this level of quality assurance problems with the ALCM airframe, and the F107 engine and INE, both of which possess considerably more complex designs than the Tomahawk airframe, have had a much lower level of product assurance problems. Also, there is no evidence that the airframe product assurance problems would have been substantially reduced had the project been organized in a simpler and more traditional manner with GD/C as the single prime contractor. Although the JCMPO quality control staff was at times below the desired level, ensuing GD/C engineering design and manufacturing discipline problems may have been difficult to correct with *any* reasonable staff size in the project office.

The AUR dual sourcing competition itself offers a mechanism for Tomahawk quality assurance for two reasons. First, each contractor will be required to warrant the complete Tomahawk missile. Second, the competitive split buy should offer both GD/C and MDAC added inducement to maintain a high level of quality control because past performance (including quality assurance) can be a source selection criterion used by the JCMPO for future year competitive split buy awards (up to 40 percent of the total yearly buy) between the two contractors. Without the AUR competition, however, the government's capability for correcting these quality assurance problems might be severely weakened.

Although the DCASPRO Method "D" action given to GD/C could have included cessation of hardware deliveries to the government, only formal acceptances were halted; very low rate production, and progress payments, continued. The DX priority of the project, plus the sole source position that GD/C was in at the time, surely influenced the corrective action taken by the government. Had the dual source AUR been fully implemented at that time, the other contractor would have been capable of meeting the full production requirement, giving the government greater freedom in applying sanctions.

[38]Method "D" Corrective Action letter from DCASPRO to GD/C on June 22, 1982.

IV. PROJECT OUTCOMES

It is too early to know the final consequences of the management methods described in Sec. III. Only one system (ALCM) has very much production history, and another system (MRASM) is still early in its development cycle. However, some partial and preliminary indications of project outcomes can be expressed at this time.

Unfortunately, even under the best of conditions the effectiveness of acquisition management is difficult to assess. No single criterion, or set of criteria, is universally accepted for measuring weapon system acquisition management. The most common approach is to compare the project outcomes (measured by system performance, schedule, and cost) with the goals established at the beginning of the project. While yielding quantitative answers, that approach has two obvious limitations. First, the manager at the end of the project is rarely the same person who participated in the formulation of the goals at the beginning, and thus should not be held strictly accountable for accomplishing those goals. The Joint Cruise Missiles Project is unusual in that Rear Admiral Locke was one of the key managers during the formative phase of the project, beginning in 1972, and then served as project director from 1977 (DSARC II) until mid-1982, thus completing an unbroken management term of nearly ten years. Even so, the full consequences of his management term are not yet fully discernible. Second, many changes occur from outside the project manager's sphere of control: Budgets are modified (both up and down); performance goals are changed as the threat evolves and new technological opportunities arise; schedules are stretched or compressed; and, most often, the quantities scheduled for procurement are changed, sometimes drastically. These and other changes sometimes make the final project outcome almost unrecognizable when compared with original goals, regardless of management effort.

Despite these limitations, our preliminary assessment of the project will rest mainly on comparing actual outcomes, or current projections of future outcomes (in terms of system performance, project schedule, and project cost), with the goals established in January 1977 when the JCMPO was formed and full scale development of the ALCM, SLCM, and GLCM were authorized. We will, throughout this preliminary assessment, try to indicate the effects of "external" changes, as distinct from those changes that were presumably under the control of the project director. And, to put the results in perspective, they will be compared with "typical" outcomes from other major acquisition programs conducted during the past decade.

Finally, we wish to emphasize again that this assessment is little more than a glimpse taken roughly mid-stream in the life of a large, complex acquisition project. These results will almost certainly be modified as additional events unfold and as the full consequences of earlier management policies and actions become more apparent. We encourage subsequent studies that would build on the foundation presented here and that could provide a more complete and balanced assessment of the overall project organization and management.

Our data for the performance, schedule, and cost analyses are mainly from the ALCM, GLCM, and SLCM project Selected Acquisition Reports (SARs). The MRASM has yet to reach the stage in its acquisition cycle where a SAR is required, so we conducted no analyses for that system.

SYSTEM PERFORMANCE

It is conventional wisdom that the premier goal of a project manager is to produce a system that performs well on its assigned mission. Tight schedules and cost controls mean little if the system fails in the field. We therefore first compare the performance goals stated at the beginning of full scale development with those obtained from test results as given in the March 1982 SARs. The initial approved project performance goals for the ALCM, GLCM, and anti-ship and nuclear armed land-attack SLCMs appeared in their respective December 1977 SARs, and those for the conventionally armed land-attack SLCM appeared in the December 1979 SLCM SAR.

To avoid security restrictions, we present all comparisons in the form of ratios: [test results] divided by [approved project goals]. In some cases a large ratio is desired (missile range, for example, where more is better) and in other cases a small ratio is desired (missile CEP, for example). To permit aggregating the results for several different performance parameters, and to be consistent with long-standing convention when dealing with cost results (discussed below), we inverted the ratios for such parameters as missile range so that in all cases a ratio less than unity is desirable.

Before we present the results of the analysis, two factors warrant discussion. First, no GLCM performance data had been reported in the SARs through March 1982. Consequently, a GLCM performance ratio could not be determined. The high degree of commonality between the GLCM and the nuclear armed land-attack SLCM permitted a valid approximation for the overall GLCM performance ratio to be obtained by simply using that calculated for the nuclear armed land-attack SLCM.

Second, upon examining the reported SAR test results, we found the values for one performance parameter were consistently different (poorer) than those obtained in flight tests a year or more before the March 1982 SAR. Because of this unexplained discrepancy, which did not occur in any of the other performance parameters, we eliminated that performance parameter from the subsequent analysis. Had we included it, using the flight test results, the performance ratio for each of the SLCM variants would have improved (become numerically smaller).

Aggregating the ratios for all performance parameters reported in the SAR for each missile system yielded values of 0.94 for the ALCM, 0.86 for the anti-ship SLCM, 0.79 for the nuclear armed land-attack SLCM, and 0.85 for the conventionally armed land-attack SLCM. That is, in all cases the aggregate measure of system performance was better than that established as a goal in the SARs at the beginning of FSD.

In a previous study, performance ratios were obtained for 11 programs that entered development during the 1970s and that had passed DSARC III by 1978 (the cut-off date of that study).[1] The average ratio of all performance parameters determined in that earlier study was 1.04.[2] The performance of the ALCM and SLCM variants (hence the GLCM) was clearly better than that of the aggregate average of our earlier sample. Because only the ALCM had passed DSARC III before our March 1982 SAR cutoff, performance improvements in the SLCM variants and the GLCM over the results presented here may occur before their

[1]Dews et al., *Acquisition Policy Effectiveness*. Those programs included in the analysis were the Army UH-60A helicopter and the M-198 howitzer; the Navy Aegis fire control radar, CAPTOR torpedo-mine, AIM-9L Sidewinder missile, AIM-7F Sparrow missile, and Harpoon missile; and the Air Force F-15 aircraft, AWACS (E-3A) aircraft, A-10 aircraft, and F-16 aircraft.

[2]The value actually reported was 1.00. However, that was achieved by eliminating "outlier" values that exceeded 2.5 or were less than 0.5 for individual performance parameters. For the comparison presented here, the earlier data were recalculated to include the outliers, yielding the overall aggregate value of 1.04 shown above.

DSARC III reviews; thus the average ratios for these cruise missiles may become better with time. Consequently, at least based on this analysis, the cruise missiles now being developed have demonstrated a substantial degree of performance maturity relative to their initial approved project goals and to other typical DoD weapon systems.

In addition to the performance data reported in the SARs, two significant accomplishments are worth noting. The project produced the first target hit by an extended range anti-ship cruise missile (January 15, 1981) and the first sinking of a ship by an extended range anti-ship cruise missile (July 18, 1982).[3]

PROJECT SCHEDULE

Schedule compliance was measured in a manner analogous to the approach used above for system performance. Schedule goals stated in the initial approved program were compared with those achieved and given in the March 1982 SAR. The initial approved schedule goals for the ALCM, GLCM, and anti-ship and nuclear armed land-attack SLCMs appeared in their December 1977 SARs, and those for the conventionally armed land-attack SLCM appeared in the December 1979 SLCM SAR.

A ratio was calculated for each schedule parameter by comparing the number of months actually taken to accomplish it from the beginning of full scale development with the number of months originally scheduled in the initial approved program. The average of the individual ratios determined for each cruise missile variant was then obtained to yield an overall schedule ratio. Only schedule parameters with actual achievements reported in the SARs up to March 1982 were included.

The ALCM was the only cruise missile variant to have passed DSARC III before our March 1982 SAR cutoff date. The average of the ALCM schedule ratios was 1.05, representing a slight schedule slip compared with the initial approved program schedule.[4] A revised schedule for the first FSD test flight, IOT&E start, and first operational platform launch for both the AGM-86B and the AGM-109, and the completion of IOT&E, was given in the March 1978 ALCM SAR. The reason stated for this was: "Changed dates are a result of a four month delay in receiving the FY78 supplemental budget authorization for the ALCM program." This was an externally induced schedule delay, so we also calculated the average ALCM schedule ratio using revised dates for the previously mentioned variables, and the existing dates for all other variables. The result of this analysis was an ALCM schedule ratio of 1.04, or only marginally better than in the unmodified case.

The proposed DSARC III date for the ALCM, as defined at the time of DSARC II, was May 1980. The actual DSARC III occurred in April 1980. Because this included the ALCM flyoff, not envisioned at DSARC II, the net schedule compliance was better than the average schedule ratio value indicates. In addition, the FAC date was achieved on time and, at the time of writing, there is every indication that the December 1982 IOC date will be met.

The overall ALCM schedule ratio of 1.05 can be compared with an aggregate schedule ratio obtained for 10 programs from the 1970s, which was 1.13. The schedule ratios for those

[3]The longest range U.S. anti-ship cruise missile target hit prior to this was approximately 1/4 the range (50 n mi) with a Harpoon. In all, five ship target hits were recorded by anti-ship SLCMs between January 1981 and July 1982 over ranges of 100 to 250 n mi from the launch point.

[4]In this analysis the June 1981 IOC date given in the December 1977 ALCM SAR was made equivalent to the current First Alert Capability (FAC) date (September 1981). The rationale for this was the following statement in the December 1977 ALCM SAR: "The IOC of June, 1981, is currently under review. The project start delay from November, 1977, to February, 1978, may require a three to four month slip in (the) IOC (date)."

programs were derived using achieved schedule data reported in their March 1978 SARs a part of a previous study.[5]

Determination of the GLCM and SLCM schedule ratios did not prove possible. In th GLCM case, only one schedule event was reported being completed (besides the DSARC I review) in the March 1982 SAR, although five other schedule events from the initial ap proved program were to be performed before that date. Four schedule changes occurred tha slipped the GLCM project IOC 21 months from the March 1982 date given for the initiall approved project. The initial IOC date change, from May 1982 to March 1982, was reported i the March 1978 GLCM SAR. The reason given was "IOC date has been corrected to reflec the approval date contained in the (Air Force) Program Management Directive (PMD)." Th second IOC date change, from March 1982 to September 1982, was reported in the Septembe 1978 GLCM SAR, which stated that the "September 1982 IOC (was) directed by (the) Augus 21, 1978 Air Force amended PMD." The third IOC date change, from September 1982 to Ma 1983, was reported in the December 1978 GLCM SAR. The reason stated was that the "IOC was revised to reflect decisions during the FY80 budget cycle." The final IOC date change from May 1983 to December 1983, was reported in the September 1978 GLCM SAR, whic said that the "December 1983 IOC (was) directed by (the) August 29, 1979 (Air Force) amend ed PMD." These four changes in the GLCM IOC date, and the remainder of the schedule were largely beyond the control of the JCMPO.[6] Given the diverse and high level source o these changes in the GLCM schedule, it is somewhat noteworthy that the GLCM IOC dat has not been further delayed. As of the March 1982 GLCM approved program, the DSARC II and IOC events are scheduled for May and December 1983, respectively. At the present time every indication is that these two important GLCM project milestones will be achieved o time.

Quantification of the project schedule for the SLCM proved even more difficult to perforn than for the GLCM because of three different missile variants, coupled with two differen launch platform types each, for a total of six different missile/launch platform type combina tions. The schedule, including the IOC, of both land-attack SLCM variants was strongl affected by external influences from the President, the Congress, and the NATO High Leve Group. Similarly, the anti-ship SLCM was affected by external events, including reduction in the FY80 budget. These complications, and the resulting difficulty they would impose o the SLCM schedule ratio calculations, prevented our performing this analysis. Instead, w present a brief summary showing how the approved program IOC dates of the SLCM variant have changed with time. This will provide the reader with an indication of the degree o complexity present in the SLCM variant project schedules.

The initial approved program IOC dates for the anti-ship and nuclear armed land-attac SLCMs were July 1981 and January 1982 respectively for the submarine-launched version and July 1982 for the ship-launched versions. Because the conventionally armed land-attac SLCM was not part of the DSARC II briefing or decision, it was not included in the SLCM Development Estimate.

In the December 1978 SLCM SAR, the approved program IOCs for the anti-ship missil [illegible] changed to July 1982 for the submarine-launched version and July 1983 for the ship

[illegible] *[illegible]sition Policy Effectiveness.* The programs used for the schedule analysis were the same as thos [illegible] analysis, except that the AIM-7F Sparrow missile was deleted because it suffered very larg [illegible] of events beyond the control of the project office. Although such externally induced sched [illegible] including the Sparrow would have biased the resulting aggregate distribution mean an [illegible]

[illegible] the reasons for these schedule changes is discussed in Appendix I.

launched version, and to "Not Scheduled" for the nuclear armed land-attack missile. The rationale given in the SAR was that the "Anti-ship missile (was) delayed due to (a) delay in (the) first production from FY80-FY81, (the nuclear armed) land-attack (missile) is no longer scheduled because production is not planned."

In the December 1979 SLCM SAR, the approved program for the nuclear armed land-attack missile IOC was changed to "To Be Determined," and the conventionally armed land-attack variant was introduced as a stand-alone project with an approved program IOC of January 1982 for the submarine-launched version and July 1983 for the ship-launched version. From the December 1979 through the March 1982 SLCM SARs, reference to land-attack SLCMs includes both conventionally armed and nuclear armed variants, although the quantity scheduled for production is greater for the former type.

Although an analysis of the SLCM variants schedules could not be performed, the anti-ship and conventionally armed land-attack variants appear ready to meet their IOCs as of the time of this report. In this, as in the GLCM project, an evaluation of the schedule criteria in terms of the important IOC dates will have to addressed in the future.

PROJECT COSTS

Despite exemplary accomplishments in terms of developing systems that achieve (or exceed) performance goals, and with modest schedule slips, project cost growth is the measure that receives public (and Congressional) attention. We will show the changes that have been recorded in the SAR cost projections for the cruise missile projects through March 1982 together with a brief discussion of the primary reasons that were given for the changes. Additional information is contained in Appendix I.

Cost changes are most easily described in terms of cost growth ratios (defined as the Current Estimate divided by the baseline Development Estimate established at DSARC II, both in base year (FY77) dollars). However, comparison of such cost growth ratios for several programs can be misleading if the programs cover different time spans. Program cost tends to increase with the passage of time. Although one would expect a decline in the annual growth rate following the entry of the production phase, recent experience has shown that because of schedule stretch-outs and, in some cases, a continuing effort to improve the performance of the equipment to match the growing threat, this flattening of the cost growth curve is postponed until a very late period in a typical program's life cycle.[7] Therefore, while noting the overall cost growth experienced by each project to date, we will emphasize the average annual *rate* of cost growth for comparison purposes.

We made two adjustments in the raw cost data when generating the cost ratios and growth rates presented below. First, all cost values were translated into constant base year (FY77) dollars, thus removing the effects of inflation. Second, the procurement cost changes were normalized to the baseline (Development Estimate) quantity.[8]

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[7]Although program cost variations over time periods as brief as one calendar quarter can be obtained from the SARs, analysis over a longer period of time is often needed to obtain an accurate estimate of underlying trends.

[8]Missile and other procurement cost changes were normalized by scaling them according to the percentage difference between the missile baseline quantity and the quantity assumed in the cost change calculation. Details of the procedure are explained in Appendix I.

ALCM Program

The ALCM program exhibited a normalized cost ratio of 1.23 for the total program through March 1982, most of the growth occurring in 1980 and 1981. At least some of the cost growth during that period can be attributed to the ALCM program management transition from the JCMPO to the Air Force, which was nearly complete by June 1980. This represents an annual cost growth rate of 4.4 percent. The average annual growth rate of the ALCM program *development phase* cost was 7.8 percent. The *procurement phase* cost exhibited an overall growth rate of 3.0 percent. During this phase the annual growth rate of ALCM *missile* procurement cost was only 2.0 percent; it was 11.8 percent for support equipment.

Almost half of the total program cost growth was attributed to inaccuracies in the original DE projection, caused in some measure by the change from the AGM-86A, briefed at the DSARC II, by the AGM-86B, and finally by the AGM-86B as modified to reduce production cost. However, the first large procurement underestimate was revealed in the December 1980 SAR as an estimating change. It amounted to $238.7 million.[9] Other important increases in the estimating category were attributed to refinements (June and September 1981 SARs) and escalation adjustment (December 1980 SAR). The other notable increase was in the support area, primarily for warranties (March and September 1981 SARs) (although these are expected to yield long run cost savings) and to cover underestimates of support equipment costs (December 1978 SAR). In fairness to the other cruise missile variant projects, it should be pointed out that the development of the launch equipment for the ALCM is not entirely covered by ALCM program funding. Some of it is to be found in the modification budget for the B-52s and in the acquisition costs of the forthcoming B-1B bomber. Some funding was allocated for the ALCM that was used for B-52 modifications (e.g., pylons).

SLCM Project

The SLCM project experienced a total normalized cost ratio of 1.54 through March 1982. This represents an annual cost growth rate of 10.4 percent. The average annual growth rate of the SLCM program *development phase* cost was 7.5 percent. The *procurement phase* cost exhibited an overall growth rate of 12.6 percent. The average annual growth rates in the procurement cost of the anti-ship and the two land-attack SLCM variant *missiles* were 2.8 percent each. Launch equipment procurement cost experienced an average annual change of 50.2 percent and support equipment 41.7 percent.

The large increases in the ship launch equipment and other support categories were in large part due to the change in the quantity and types of ships, hence in their associated launch equipment and peculiar support equipment. Similarly, modifications to the ABL to support these launch platform changes produced a substantial increase that was recorded in the engineering variance category (June 1978 SAR). At least some of the air vehicle cost growth is the result of the large changes in expected production quantity and in project schedules since the development estimate was made.[10] Finally, SLCM development cost

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[9]The December 1981 SAR data indicate that the land-attack SLCM unit cost decreased to $.83 million, while the GLCM unit cost decreased $.80 million. Presumably, a part of this GLCM cost reduction was due to learning curve effects for the common missile components and a more efficient production rate, although this was not acknowledged in the GLCM SAR. The lack of a similar decrease in ALCM costs suggests offsetting cost growth in its airframe, the only major subsystem that is not common to the other land-attack cruise missiles.

[10]In the ALCM and GLCM programs, large procurement quantity changes have occurred only once between the Development Estimate and mid-1982. This reflects, in part, the Air Force's practice of programming the entire anticipated buy at the time of DSARC II. Additional information on variations in procurement quantity is given in Appendix I.

increases were partly due to development of the conventionally armed land-attack version, which was not part of the initial Development Estimate.

GLCM Program

The GLCM program experienced a total normalized cost ratio of 1.93 through March 1982. This represents an annual cost growth rate of 17.6 percent. The average annual growth rate for the GLCM program *development phase* was 44.1 percent, almost entirely caused by cost growth in the launch and support equipment. The total GLCM program *procurement* cost had a net average annual growth rate of 13.1 percent, with the increase due solely to non-missile related cost increases. The average annual rate of growth for procurement cost of the GLCM *missile* was −2.7 percent, while rates for procurement of the launch equipment and other support equipment were 86.4 and 16.8 percent, respectively.

In the GLCM program, credit was given as an estimating variance change (December 1978 SAR) for the greater than expected benefit from SLCM commonality with the GLCM, amounting to $80 million. There was extensive growth in the cost of the launch and peculiar support equipment, however, as noted above. Experience gained in the SLCM project provided a good basis for estimating the cost of the GLCM missile, and of test and maintenance devices, but not for the kind of enduring and secure off-base mobility system required for the nuclear-armed GLCM. The simple van and trailer mobility system that was assumed in the baseline cost estimates evolved into a much more elaborate system that stressed flexible control and survivability in an intensely hostile war environment. As of the March 1982 SAR, the necessary refinements and equipment additions had added more than $700 million to the GLCM total procurement cost.

Comparison with Other Programs

To put these cost growth rates in perspective, we compare them with those of other major acquisition programs. An unpublished Rand survey of 20 "mature" acquisition programs (at least three years past the beginning of full scale development) developed during the 1970s yielded an average annual growth rates of 6.3 percent for the development phase, 3.8 percent for the procurement phase, and 7.2 percent for the total program.[11] As those average growth rates were based on data in the March 1981 SARs (the cutoff for our aggregate SAR cost data base), they may not accurately reflect the current overall growth rate and therefore can be regarded only as a general indication of what other current military acquisition programs have experienced.

To simplify the comparison of cost growth rates for the ALCM, GLCM, and SLCM projects with the rates for other major acquisition programs, the values quoted above are summarized in Table 4. Time histories of the cost growth in the ALCM, GLCM, and SLCM

[11]The data base used to determine trends in total program cost and in development cost includes the Army Patriot, Hellfire, UH-60, AH-64, XM-1 tank, Roland, CLGP, DIVAD gun, and M-198 howitzer: Navy F-18, CAPTOR, Harpoon, 5 inch guided projectile, SURTASS, and TACTAS; and the Air Force DSCS III and E-3A, A-10, F-15, and F-16 aircraft. Trends in procurement cost growth were based on the Patriot, UH-60, XM-1, Roland, CLGP, M-198, CAPTOR, Harpoon, E-3A, A-10, F-15, and F-16; the other systems had insufficient production experience. The cost growth ratios were calculated in terms of base year constant dollars normalized to reflect their Development Estimate baseline quantities. The annual rate is a simple linear regression of the data points with the Y-intercept (DSARC II date) designated as 1.0.

Table 4

AVERAGE ANNUAL COST GROWTH RATES
(Percent)

Item	ALCM	GLCM	SLCM	Average of Other Programs
Development	7.8	44.1	7.5	6.3
Procurement	3.0	13.1	12.5	3.8
Total program	4.4	17.6	10.4	7.2

projects from December 1977[12] through March 1982 are given in Figs. 11, 12, and 13.[13] Separate histories are shown for missile, support, and (except for ALCM) launch equipment, and total procurement, as well as total program.

The average annual growth rate of the ALCM total program falls below the 20-program aggregate average rate, whereas the rates for the SLCM and GLCM programs are on the high side. Breaking down these total program average annual cost rates to the level of the above-noted acquisition phases and categories shows that each of the cruise missile *air vehicles* falls below the aggregate cost growth curves, and the other categories lie above it. Although the support categories of the ALCM and GLCM programs had only moderate cost increases, that for the SLCM project had a large increase (41.7 percent). The launch equipment for the GLCM and SLCM programs also had very large cost increases. The factors that led to their cost growth were mostly beyond the control of the JCMPO, so they provide an example of increases in total program cost that can result from external influences.

Although the 20 programs in the aggregate data set vary considerably in their degree of complexity, their average cost growth rate does provide an initial benchmark against which the cruise missile experience can be measured. Only the ALCM program has reached the DSARC III stage at this time, so a follow-on analysis should be performed in the future to measure the cost growth rates of the GLCM and SLCM programs when they, too, have reached this stage in their acquisition cycles.

Despite the overall cost growth in these projects, costs would probably have increased even more without the use of several cost containment methods such as procurement phase dual sourcing and the high degree of subsystem commonality among the cruise missile variants. Similarly, the use of warranties is expected to yield net cost savings throughout the lifetime of the deployed cruise missiles.

The extensive use of subsystem commonality between the cruise missile variants also permitted the development of other variants with reduced funding levels. Furthermore, cost

[12]DSARC II occurred in January 1977 for these projects, but the first SARs were issued in December 1977. Those first SARs showed identical cost values for Current Estimate and Development Estimate. We assume that the Development Estimate values reflect estimates made at DSARC II (nearly a year earlier), and that no cost growth occurred during that first year.

[13]The data presented in these figures are derived and explained in Appendix I.

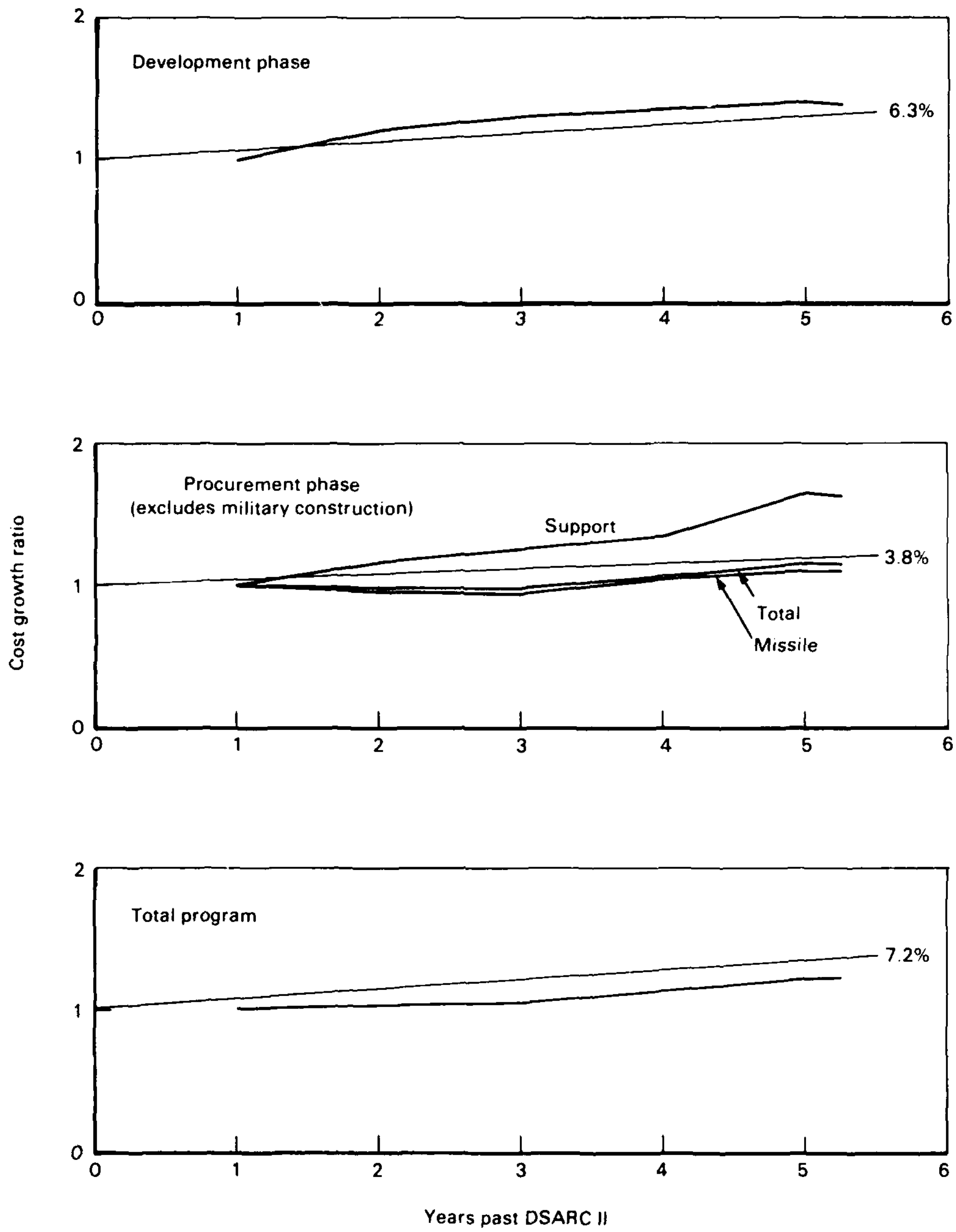

Fig. 11—ALCM program cost growth

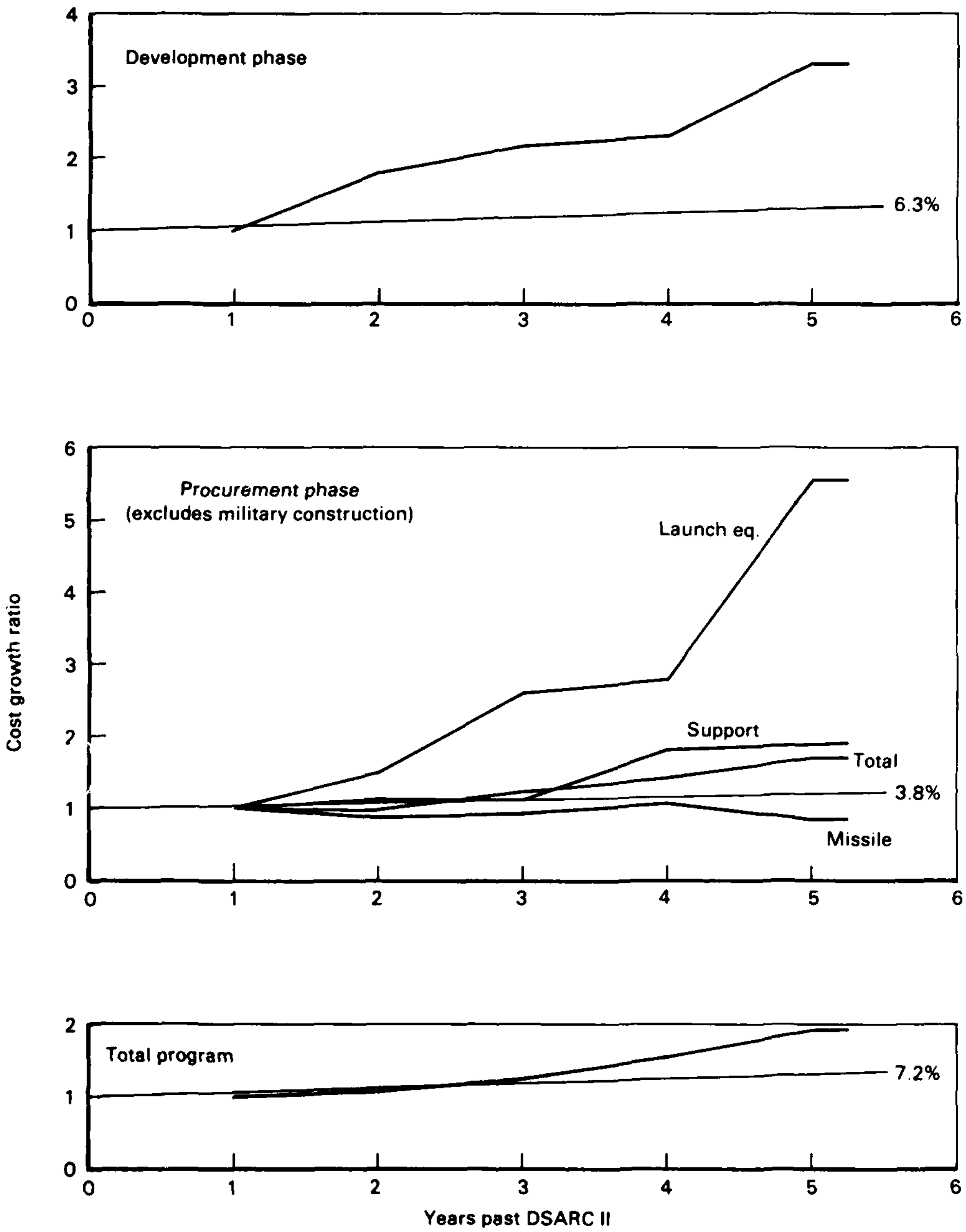

Fig. 12—GLCM program cost growth

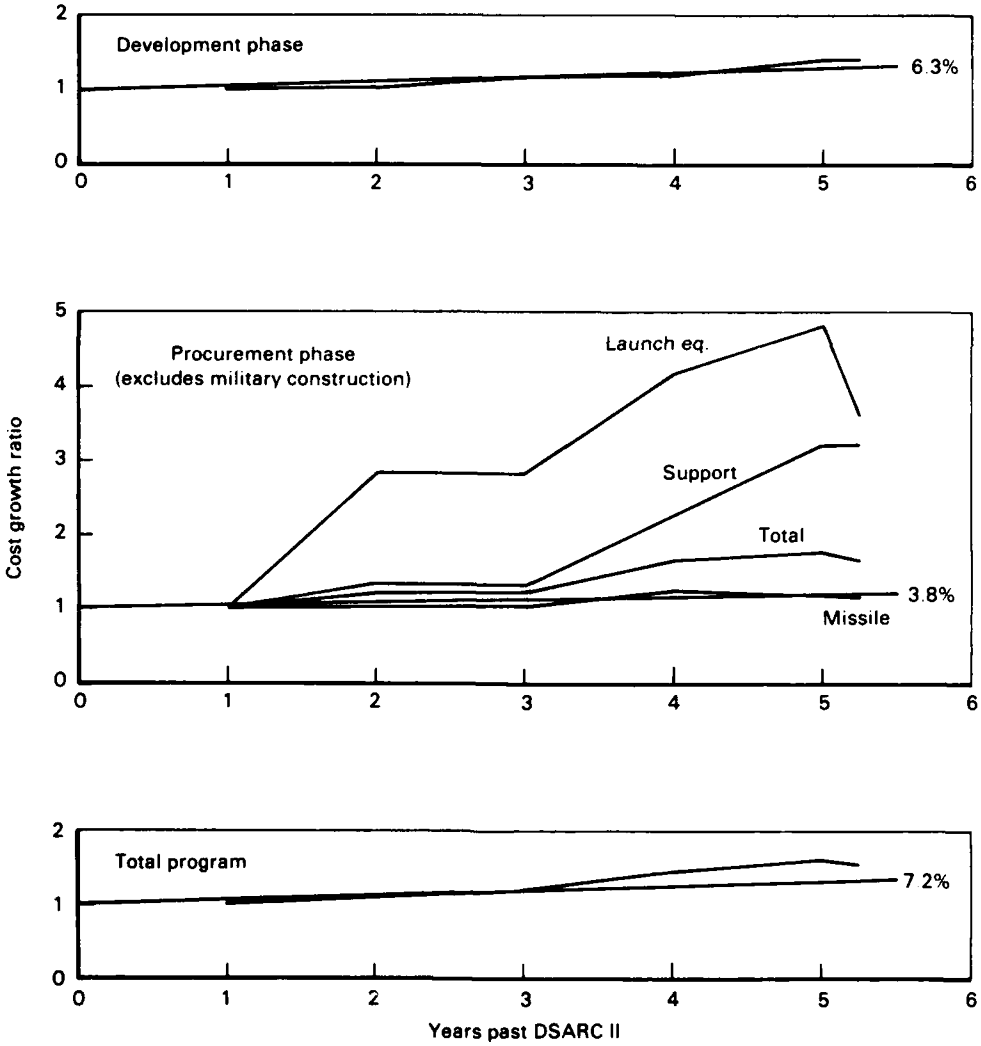

Fig. 13—SLCM program cost growth

savings have already been realized in the development of the AGM-109, GLCM, conventionally armed land-attack SLCM, and MRASM by using the nuclear armed land-attack SLCM as an air vehicle base.

DMA Cruise Missile Support Costs

The cost for DMA cruise missile support between FY78 and FY83 has been estimated by DMA to be $163 million ($ FY82). When projected through FY90, the costs are expected to total between $373 million and $443 million ($ FY82), or roughly 5 percent of the overall joint cruise missiles project cost. That cost, however, is incurred by DMA and is not reported

as a JCMPO expenditure. A description of the derivation of those DMA cost estimates is contained in Appendix I.

The costs incurred by DMA in support of the joint cruise missiles project have also shown some growth. The actual FY78-FY83 costs and the projected FY84-FY90 total cost estimate are considerably higher than those advanced during the earlier stages of the cruise missile program. Differences between earlier and currently projected total data base costs are the result of a number of factors. These include: (1) an expansion of area coverage due to increased Theater Commander interest as the GLCM and conventionally armed SLCM were introduced; (2) the lack of DMA product production experience at the time of the initial estimates; (3) the delay in approving the use of an alternative TERCOM source data form; (4) shifts in user area priorities based upon changing DoD/JCS policy; (5) the lack of usable preferred source material in some areas; (6) the accelerated production required by late requirement identification; and (7) a change in the relative numbers of TERCOM map types (the number of landfall, enroute, and terminal maps). Similarly, the approved yearly production schedule rates for the early years consistently fell below original estimates, particularly for TERCOM. This was a consequence of the same factors that led to increased program cost. However, the FY81-FY86 production program is now back in phase, and production rates are meeting or exceeding the original predicted schedule.

One component of the projected DMA cost is for generation of the TERCOM data base. The $70 million to $80 million estimated by DMA for this task is substantially less than the estimates of Baker ($165 million) and Toomay ($1 billion).[14] However, both DMA's historical costs and their projections are based on requirements for the nuclear armed land-attack cruise missiles (ALCM, GLCM, and SLCM) and only minimal conventionally armed land-attack requirements. As targeting and employment concepts for the conventionally armed land-attack cruise missiles (MRASM and SLCM) become better defined, and should they include large Third World options, the DMA TERCOM support costs could go up considerably and become a much greater portion of DMA total system costs.

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[14]John C. Baker, "Program Costs and Comparison"; and John C. Toomay, "Technical Characteristics," in Richard K. Betts (ed.), *Cruise Missiles*, The Brookings Institution, Washington, D.C., 1981.